

CUE 03-0041

North Carolina Cooperative Extension Service

NC STATE UNIVERSITY

College of Agriculture and Life Sciences

Department of Entomology

Campus Box 7613

Raleigh, NC 27695-7613

AUG 11 2003

919.515.2703 (phone)

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August 8, 2003

US Environmental Protection Agency
Methyl Bromide Critical Use Exemption
Office of Pesticide Programs
911 Bay, BEAD
1921 Jefferson Davis Highway
Arlington, VA 22202

Dear Sir/Madam:

Please find enclosed the Methyl Bromide Critical Use Exemption application on behalf of the Southeastern Pepper Consortium. This request is for a critical use exemption for the use of methyl bromide for pepper production.

Sincerely,

Stephen J. Toth, Jr.

Stephen J. Toth, Jr.
Extension Entomologist and
Pest Management Information Specialist

Enclosures

03-0041



Steve Toth
<steve_toth@ncsu.edu>
>

08/19/2003 12:01 PM

To: Marta Montoro/DC/USEPA/US@EPA
cc: Ron Stinner <Ron_Stinner@ncsu.edu>, Steve Toth
<Steve_Toht@ncsu.edu>, Kenneth Sorensen
<Kenneth_Sorensen@ncsu.edu>, Jim Walgenbach
<Jim_Walgenbach@ncsu.edu>, Bill Jester
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"Burleson.smith" <Burleson.smith@usda.gov>, pattfarm
<pattfarm@prodigy.net>, rboozzer
<rboozzer@acesag.auburn.edu>, Ed_Estes <Ed_Estes@ncsu.edu>,
mallan@arvesta.com, gbarnes@ncfb.net, wnesmith@uky.edu
Subject: Correction of MeBr CUE Applications for SE Cucurbits, Peppers
and Tomatoes

Marta:

The Methyl Bromide Critical Use Exemption applications from the Southeastern Cucurbit Consortium, Southeastern Pepper Consortium, and Southeastern Tomato Consortium contained an error on Worksheet 1 of each application. For the question "Is this information Confidential Business Information?", the "Yes" box was checked. In each case, the "No" box should have been checked. The applications from the Southeastern Cucurbit Consortium, Southeastern Pepper Consortium, and Southeastern Tomato Consortium do not contain any information considered to be Confidential Business Information.

Attached is an Excel file that contains corrected copies of Worksheet 1 for the Southeastern Cucurbit Consortium, Southeastern Pepper

03-0041

Consortium, and Southeastern Tomato Consortium. Please substitute these worksheets for the ones previously sent by electronic mail. If you need signed copies, let me know and I will secure the signatures and mail signed copies to you.

Thank you for your assistance.

Steve Toth
Extension Entomologist and
Pest Management Information Specialist
North Carolina State University



Worksheet 1 Corrections.x

Worksheet 1. Contact and Methyl Bromide Request Information

The following information will be used to determine the amount of methyl bromide requested and the contact person for this request. It is important that we know whom to contact in case we need additional information during the review of the application.

Is this information Confidential Business Information?

Yes

☒

No

☐

If yes, the applicant assumes responsibility for the secure transmission of electronic submissions.

Discriminated
CEI 8/19/03
See Act. 1

Applicant Name Southeastern Pepper Consortium

Primary Contact

Contact Name

Dr. David W. Monks

Address

Department of Horticultural Science
Campus Box 7609, N. C. State University
Raleigh, NC 27695-7609

Specialty

(Check One)

Agronomic

☒

Economic

☐

Daytime Phone

919-515-5370

Cell

919-218-1822

E-mail Address

David_Monks@ncsu.edu

Fax

919-515-7747

Alternate Contact

Contact Name

Mr. Stephen J. Toth, Jr.

Address

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Campus Box 7613, N. C. State University
Raleigh, NC 27695-7613

Specialty

Agronomic

☒

Economic

☐

Daytime Phone

919-515-8879

Cell

none

E-mail Address

Steve_Toith@ncsu.edu

Fax

919-515-7746

I certify that all information contained in this document is factual to the best of my knowledge.

Signature

David W. Monks

Date 7-Aug-03

Print Name

David W. Monks

Title Extension Weed Specialist

Information in this application may be aggregated with information from other applications and used by the United States government to justify claims in the national nomination package that a particular use of methyl bromide be considered "critical" and authorized for an exemption beyond the 2005 phaseout. Use of aggregate data will be crucial to making compelling arguments in favor of critical use exemptions. **By signing below, you agree now to assert any claim of confidentiality that would affect the disclosure by EPA of aggregate information based in part on information contained in this application.**

Signature

David W. Monks

Date 7-Aug-03

Print Name

David W. Monks

Title Extension Weed Specialist

Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information. Public reporting burden for this collection of information is estimated to average 324 hours per response and assumes a large portion of applications will be submitted by consortia on behalf of many individual users of methyl bromide. An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a current OMB control number.

Worksheet 1. Contact and Methyl Bromide Request Information

- 1. Location** (Enter the state, region, or county.)
Alabama, Arkansas, Kentucky*, Louisiana*, North Carolina, South Carolina, Tennessee and Virginia
- 2. Crop/Crop Grouping** (Include all crops/crop groupings that benefit from an application of methyl bromide in a fumigation cycle. For a definition of fumigation cycle see Worksheet entitled "Definitions".)
Peppers
- 3. Range of acres farmed by growers included in this application**
(Insert number or percentage of users in each category)
- | | | |
|----------------|-----------------|----|
| 0 - 25 acres | 100 - 200 acres | 10 |
| 25 - 50 acres | 200 - 400 acres | 1 |
| 50 - 100 acres | over 400 acres | |
- 4. Climate Zone** (Indicate the climate zone designation by reviewing the U.S. climate zone map located at the end of this workbook or online at <http://www.usna.usda.gov/Hardzone/ushzmap.html>.)
Zones: 1 2a 2b 3a 3b 4a 4b 5a 5b 6a 6b X
(check all that apply) 7a X 7b X 8a X 8b X 9a 9b 10a 10b 11
- 5. Soil Type & Organic Matter** (Indicate the soil type and percent organic matter where methyl bromide would be applied.)
(check all that apply)
- | | | | | | | |
|-----------------|----------|-----|----------|----|----------|--|
| Soil Type: | Light | 90 | Medium | 10 | Heavy | |
| Organic Matter: | 0 to 2 % | 100 | 2 to 5 % | | over 5 % | |
- 6. Is this applicant eligible for Quarantine and Preshipment (QPS) uses of methyl bromide?** Yes ☐ Pounds ☐
No ☒
- 7. Has this applicant previously applied for Critical Use Exemption of methyl bromide?** • Kentucky and Louisiana have been added to Consortium in 2003 Yes ☒ CUE # 02 0041
No ☐
- 8. What is the amount of methyl bromide being requested by this application ? (Do NOT include QPS amounts)**
If a consortium is submitting this application, the data should be the total for the consortium.

Year	Total Pounds Active Ingredient (a.i.) of Methyl Bromide	Total Area to be Treated
2005	464,980 lbs.	3,470 Acres
2006	495,800 lbs.	3,700 Acres
2007	529,300 lbs.	3,950 Acres

- 9. Please explain why there may be variations in the pounds or acres treated from year to year.**
An increase in the acreage of peppers produced in the Southeastern U. S. is projected from 2003 through 2007 (see Tables 1 and 2). The reasons vary from state to state; however, they include shift in acreage from tobacco and peanut production to the production of peppers and other vegetable crops, etc. (see Attachment 1).
- 10. Please explain why methyl bromide is being requested.**
In the absence of technically and economically-feasible alternatives, methyl bromide will be needed by pepper producers. It is uncertain at this time when suitable alternatives will be available and transferred to producers. Thus, the Consortium is requesting three years of exemption.
- 11. Do you have access to recycled methyl bromide?** Yes ☐ Lbs
No ☒ If yes, please specify amount (in pounds).
- 12. Do you anticipate that you will have any methyl bromide in storage after January 1, 2005?** Yes ☐ Lbs
No ☒ If yes, please specify amount (in pounds).

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Contact Name

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Alternate Contact

Contact Name

Mr. Stephen J. Toth, Jr.

Address

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Specialty

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Fax

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I certify that all information contained in this document is factual to the best of my knowledge.

Signature

Date 7-Aug-03

Print Name

David W. Monks

Title Extension Weed Specialist

Information in this application may be aggregated with information from other applications and used by the United States government to justify claims in the national nomination package that a particular use of methyl bromide be considered "critical" and a

Signature

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Print Name

David W. Monks

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(check all that apply) 7a X 7b X 8a X 8b X 9a 9b 10a 10b 11
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(check all that apply)
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|-----------------|----------|-----|----------|----|----------|--|
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9. **Please explain why there may be variations in the pounds or acres treated from year to year.**
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No ☒ If yes, please specify amount (in pounds).
12. **Do you anticipate that you will have any methyl bromide in storage after January 1, 2005?** Yes ☐ _____ Lbs
No ☒ If yes, please specify amount (in pounds).

Table 1. Methyl Bromide Use on Southeastern Peppers

Year	Acreage on Which Methyl Bromide is Applied										Formulated Product ¹ (lbs.)	Methyl Bromide Percentage	Methyl Bromide (lbs. A.I.)
	NC	VA	TN	SC	GA	AR	AL	LA	KY ²	Total			
2002	1,100	300	300	350	#	50	200	150	0	2,450	490,000	67%	328,300
2001	1,000	250	100	300	#	50	150	150	0	2,000	400,000	67%	268,000
2000	1,000	300	100	300	#	50	100	150	0	2,000	400,000	67%	268,000
1999	900	400	100	300	#	50	200	225	0	2,175	435,000	67%	291,450
1998	800	400	100	300	#	50	200	200	0	2,050	410,000	98%	401,800
1997	700	400	100	300	#	50	150	300	0	2,000	400,000	98%	392,000

¹ Total acres x 200 lbs. of formulated product

² No acreage in Kentucky treated with methyl bromide specifically for peppers, but some acreage planted as second crop or last minute acreage adjustment due to changing markets and reported with tomatoes

Georgia is not a part of the Southeastern Pepper Consortium (application will be filed independently for peppers in Georgia)

Table 2. Projected Methyl Bromide Use on Southeastern Peppers ³

Year	Acreage on Which Methyl Bromide is Applied										Formulated Product ¹ (lbs.)	Methyl Bromide Percentage	Methyl Bromide (lbs. A.I.)
	NC	VA	TN	SC	GA	AR	AL	LA	KY ²	Total			
2007	1,800	550	600	500	#	100	250	150	0	3,950	790,000	67%	529,300
2006	1,700	450	550	500	#	100	250	150	0	3,700	740,000	67%	495,800
2005	1,600	400	500	500	#	70	250	150	0	3,470	694,000	67%	464,980
2004	1,500	400	450	500	#	60	225	150	0	3,285	657,000	67%	440,190
2003	1,300	350	400	400	#	50	200	150	0	2,850	570,000	67%	381,900

¹ Total acres x 200 lbs. of formulated product

² No acreage in Kentucky treated with methyl bromide specifically for peppers, but some acreage planted as second crop or last minute acreage adjustment due to changing markets and reported with tomatoes

³ Projected pepper acreage based on estimates by University specialists and industry representatives

Georgia is not a part of the Southeastern Pepper Consortium (application will be filed independently for peppers in Georgia)

Last Update: July 28, 2003

03-0041

Attachment 1

"Reasons for Projected Increases in Pepper Acreage in the Southeastern U.S. Requiring Methyl Bromide Fumigation from 2003 to 2007"

Doug Sanders
Southeastern Pepper Consortium
(CUE 02-0041: Alabama, Arkansas, Kentucky, Louisiana, North Carolina, South Carolina, Tennessee, and Virginia)

Phytophthora continues to be an increasing problem for pepper growers across the Southeastern U.S. The use of the plasticulture system helps to reduce the occurrence of this disease, thus pepper growers are shifting to more plastic mulch and need the use of methyl bromide for control of various pests. Further, although plasticulture has been used for some time, pepper growers were slow adopters and now as market pressures continue to increase, even late adopters are moving to this system. These two factors will continue to grow the demand for more plasticulture and thus more methyl bromide.

August 6, 2003

Worksheet 2-A. Methyl Bromide - Crop & Pest Information

1. Crop/Crop Grouping or Consortium

Southeastern Pepper Consortium

2. Which month does your fumigation cycle start? (check only one)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
X				X							

Fumigation cycle for Spring pepper crop begins in January; fumigation cycle for Fall pepper crop begins in May

(Indicate when fumigation, major crop and pest management practices typically occur by shading the appropriate cells. Show a second crop if part of the fumigation cycle. If the fumigation cycle is longer than one year change the months to an appropriate interval. These tables are for annual crops but more than one crop may benefit from one methyl bromide fumigation. If application covers multiple crops/crop groupings not grown sequentially, they will need to provide this information for all crops/crop groupings. Please adjust timeline as necessary. **Please provide additional comments or description below or on a separate page.** Please begin the timeline with the first land preparation. For perennials, please begin with the year of land preparation and fumigation and indicate the years of production by yield or percentage of full production.)

2. Fumigation and Crop Timeline

Beginning Fumigation Cycle	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation	X	X	X		X	X						
Fumigation		X	X	X		X	X					
Planting			X	X	X		X	X				
Harvest					X	X	X	X	X	X	X	
Fallow									X	X	X	X
Other Key Crop Steps												
Other Key Pest Steps												

Continuation of Fumigation Cycle (if needed)	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 13	Month 14	Month 15	Month 16	Month 17	Month 18	Month 19	Month 20	Month 21	Month 22	Month 23	Month 24
Land Preparation												
Fumigation												
Planting												
Harvest												
Fallow												
Other Key Crop Steps												
Other Key Pest Steps												

Comments:

Much of the pepper crop is double-cropped with other crops (i.e., cucurbits). The fumigation with methyl bromide provides pest management for the pepper crop and also the second crop. Note that these "double-cropped" cucurbit acres are not included in the acreage reported in the application from the Southeastern Cucurbit Consortium.

There are two distinct pepper crops planted on different fields, a Spring crop (fumigation cycle begins in January) and a Fall crop (fumigation cycle begins in May). Methyl bromide is applied 1 time per year on an individual field.

Worksheet 2-A. Methyl Bromide - Crop & Pest Information

3. Target Pest(s) or Pest Problem(s):

(Please identify the top target pests or pest problems. Provide at least common name and genus and species if possible. Additional pests or pest problems can be provided as an attachment.)

	Common Name	Genus
Pest 1	Yellow and purple nutsedge	<i>Cyperus esculentus</i> and <i>Cyperus rotundus</i>
Pest 2	Root knot nematodes	
Pest 3	Pythium root rot	
Pest 4		
Pest 5		

4. Pest Economic Threshold

(Please provide the economic threshold information for each pest. Describe year and source of information such as survey or expert estimate.)

	Threshold	Units (e.g. pests/sq ft)	Year	Source
Pest 1	none determined			David Monks, North Carolina State University
Pest 2				
Pest 3				
Pest 4				
Pest 5				

5. Target Pest Infestation

(Please estimate the percentage of the consortia's total growing area with a moderate to severe problem with these pests. Describe source of information such as a survey or expert estimate.)

	Percentage of Total Growing Area	Source
Pest 1	approx. 30 %	David Monks, North Carolina State University
Pest 2	%	
Pest 3	%	
Pest 4	%	
Pest 5	%	

6. Representative User :

(Please provide descriptive factors regarding your operation.)

Average Farm Size 1,000 Acres

Average acres in this crop 100 Acres

Average Area Treated with Methyl Bromide: 80 Acres

Describe a few crops that could follow this crop: cucurbits

Other descriptive factors regarding representative user:

The representative pepper grower has more than 100 acres of peppers. Peppers are the primary source of farm income for these pepper growers.

Worksheet 2-B. Methyl Bromide - Historical Use for 1997-2002

Column A:	Total Actual Pounds a.i. of Methyl Bromide Applied per Year Enter the total actual pounds active ingredient (a.i.) of methyl bromide applied. Note: This number should be the total pounds a.i. applied by the individual user or the entire consortium, for the year indicated. Include only the pounds active ingredient of methyl bromide. Do not include the pounds of chloropicrin that may be part of the same product.
Column B:	Total Actual Acres Treated per Year Enter the total actual acres treated. Note: This number should be the total actual acres treated by the individual user or total actual acres treated for the entire consortium, for the year indicated. For furrow treatment the acres should include the area between the rows as well as the area of the rows. i.e. acres treated is the area of the cultivated fields being treated including the area between rows even if they are not treated.
Column C:	Average Pounds a.i. Applied per Area per Year The average application rates in pounds a.i. of methyl bromide per area may be calculated by dividing Column A by Column B.

Year	A	B	C
	Total Actual Pounds a.i. of Methyl Bromide Applied per Year	Total Actual Acres Treated per Year	Average Pounds a.i. Applied per Acre per Year
1997	333,200 + 58,800 = 392,000 /a	1700 + 300 = 2,000 /a	196
1998	362,600 + 39,200 = 401,800 /a	1,850 + 200 = 2,050 /a	196
1999	261,300 + 30,150 = 291,450 /a	1,950 + 225 = 2,175 /a	134
2000	247,900 + 20,100 = 268,000 /a	1,850 + 150 = 2,000 /a	134
2001	247,900 + 20,100 = 268,000 /a	1,850 + 150 = 2,000 /a	134
2002	308,200 + 20,100 = 328,300 /a	2,300 + 150 = 2,450 /a	134

a = first figure is total for AL, AR, NC, SC, TN & VA (2002 Consortium); second figure is total for LA & KY (added to Consortium in 2003).

What is the frequency of methyl bromide applied per area? (1x / year, 2x / year, 1x / 3 years, etc.)

1 time per year

If there is a variation (greater than 10%) in the quantity a.i., the acres treated or average application rate from year to year, please explain the reasons for the variation.

A significant decrease in the total pounds a.i. applied in 1999 is due to a shift to the 67% methyl bromide/33% chloropicrin formulation from the 98% methyl bromide/2% chloropicrin formulation. Variations in the total pounds a.i. applied from 1999 to 2002 result from variations in the number of acres treated with methyl bromide (which relates to the number of acres of peppers planted in the states in the Consortium from year to year).

Comments:

Worksheet 2-C. Methyl Bromide - Crop/Species Yield & Gross Revenue for 2000-2002

Column A: Year	Be sure to enter the year. Use as many rows as needed for each year for all the crops/crop groupings in the fumigation cycles from 2000 to 2002. If a fumigation cycle overlaps more than one calendar year, then the year of the fumigation cycle is the year methyl bromide was applied.					
Column B: Crops/Crop Groupings	Enter all crops/crop groupings that benefit from methyl bromide in the fumigation cycle. If multiple crops/crop groupings are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the crops/crop groupings during the entire interval. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops/crop groupings grown on the same land, please indicate so in the comments section below.					
Column C: Market Categories	Enter marketing categories that determine prices received, for example, grade (size, color), timeliness (early season, late season), or end use (fresh, processing). Itemize or aggregate these factors to the extent appropriate if lack of methyl bromide would effect the yields in each category.					
Column D: Yield	Enter the yield per acre, or the proportion of total yields, obtained for that category. For perennial crops, please enter yields at full production. Be sure to indicate yields at other stages in the timeline in Worksheet 2-A.					
Column E: Units of Measurement	Enter the unit of measurement for each crop/species (lbs, cwt, carton, bin). If not by weight, specify in the comments section the average weight of the measure.					
Column F: Price	Enter average prices received by the users for that crop/crop grouping and market category. Average price over all categories can be calculated separately, if needed.					
Column G: Gross Revenue	Gross revenue per acre for each market category and or each crop/crop grouping may be calculated using the data you entered as price times yield. If revenue is not equal to price times yield, you may enter a different revenue amount, but please explain the difference in the comments section below.					

A	B	C	D	E	F	G
Year	Crops/Crop Groupings	Market Category	Yield	Unit of Measurement	Price (\$)	Gross Revenue per Acre (\$)
1997	Peppers		1,500	Box (28-30 lbs.)	\$ 8.25	\$ 12,375.00
1998	Peppers		1,500	Box (28-30 lbs.)	\$ 8.25	\$ 12,375.00
1999	Peppers		1,500	Box (28-30 lbs.)	\$ 8.25	\$ 12,375.00
2000	Peppers		1,500	Box (28-30 lbs.)	\$ 8.25	\$ 12,375.00
2001	Peppers		1,500	Box (28-30 lbs.)	\$ 8.25	\$ 12,375.00
2002	Peppers		1,200	Box (28-30 lbs.)	\$ 6.60	\$ 7,920.00
				Box = 1 1/9 bushels		

If this application is for multiple crops/crop groupings (e.g. nurseries producing evergreens, deciduous, and forbs) please indicate the proportion of land area allocated to each crop/crop grouping.

Comments:

Worksheet 2-D(1). Methyl Bromide - Baseline - Operating Costs for 2002

A	B	C	D	E
Operation / Input	Quantity Used per Acre	Units (lbs, hours, etc)	Unit Cost (\$)	Total Cost per Acre (\$)
<u>Pre-plant Operations</u>				
Land preparation				\$ 100.00
Fumigation				
product (methyl bromide)	134	lbs.	\$ 3.85	\$ 515.90
application		dollars	\$ 80.00	\$ 80.00
Irrigation				\$ 200.00
Other costs				
pepper land rental				\$ 200.00
<u>Cultural Operations</u>				
Seed / Seedlings				\$ 400.00
Fertilizer / Soil Amendments				\$ 550.00
Pesticides				
Insecticide				\$ 70.00
Herbicide				\$ 10.00
Fungicide				\$ 20.00
Nematicide				\$ 650.00
Irrigation				\$ 200.00
Labor (manual)				\$ 100.00
Fuel / Machine Labor				\$ 50.00
Other Costs				
interest on borrowed money				\$ 400.00
fixed cost				\$ 500.00
<u>Harvest Operations</u>	Constant Cost per Acre (\$)	Cost per Unit of Yield (\$)	Yield	Total Cost per Acre (\$)
Labor			1500 cartons	\$ 3,250.00
Hauling		\$ 0.50	1500 cartons	\$ 750.00
Material		\$ 0.33	1500 cartons	\$ 500.00
Grading / Packing / Storage		\$ 2.00	1500 cartons	\$ 3,000.00
Other Costs				
Total Cost (this page) - Peppers				\$ 11,545.90

Worksheet 4. Future Research Plans

Please describe future plans to test alternatives to methyl bromide. You may use this worksheet to describe all future plans.

1. Identify the top 3 to 5 target pests for your research. (David Monks, North Carolina State University)

1	Yellow and purple nutsedge	4	
2	Pigweed including Palmer amaranth	5	
3	Nightshades and groundcherries		

2. Provide a list of alternative chemicals or cultural practices that have been tested.

1	halosulfuron (Sanda)	4	chloropicrin
2	Telone C-35	5	CGA 362622 (Envoke)
3	metam sodium		

3. Prioritize the alternative chemicals or cultural practices to be tested.

1	halosulfuron	4	
2	CGA 362 622	5	
3	rotation		

4. What would be the best currently available alternative if methyl bromide were not available?

Halosulfuron is currently the best control measure for controlling nutsedges in tomatoes and certain cucurbits.
No control measure exists that will control nutsedges in peppers or strawberries.

5. Please provide an overview/timeline of the plan to transition away from using methyl bromide.

It will likely will 3 to 5 years for developing effective control measures for controlling nutsedge in these crops to replace methyl bromide.

6. Will yield/quality loss be measured?

Yes ☒ No ☐

7. Will economic impacts be measured?

Yes ☒ No ☐

8. How will you minimize your use and/or emissions of methyl bromide?

(check all that apply)

- ☐ Formulation Changes (please specify)
- ☐ Tarpaulin (High Density Polyethylene)
- ☐ Virtually Impermeable Film (VIF)
- ☐ Other
- ☐ Cultural Practices (please specify)
- ☐ Other Pesticides (please specify)
- ☐ Non-Chemical Methods (please specify)

Formulation Changes

From: _____ % methyl bromide, _____ % chloropicrin
To: _____ % methyl bromide, _____ % chloropicrin

9. What is the cumulative amount spent and the types of contributions this consortium has made to fund research to develop alternatives to methyl bromide since 1992? (e.g. consortium dues, direct research funding, etc.)

Years	Name of Organization / Research Institution	Amount (\$)
2001 - present	various companies	25,000 to 30,000

10. Other total investments, if any, made to reduce your reliance on methyl bromide?

\$ _____

(Describe each investment and its associated costs. e.g. specialized machinery, etc.)

Investment	Cost
Research (on-farm and on-research station) has been conducted to implement the use of halosulfuron in tomatoes and certain cucurbits (cantaloupes and cucumbers).	30,000 to 40,000

11. Grant requests made to USDA, EPA, state, or other funding group.

RAMP, Southern Region IPM, NC Strawberry Association, and IR-4

Worksheet 5. Application Summary

This worksheet will be posted on the web to notify the public of requests for critical use exemptions beyond the 2005 phase out for methyl bromide. Therefore, this worksheet cannot be claimed as CBI.

1. **Consortium Name:** Southeastern Pepper Consortium
 2. **Location:** Alabama, Arkansas, Kentucky, Louisiana, North Carolina, South Carolina, Tennessee, Virginia
 3. **Crop:** Peppers

Pounds of Methyl Bromide Requested 2005 464,980 lbs.

Acres Treated with Methyl Bromide 2005 3,470 Acres

6. **If methyl bromide is requested for additional years, reason for request:**

In the absence of technically and economically-feasible alternatives, methyl bromide will be needed by pepper producers. It is uncertain at this time when suitable alternatives will be available and transferred to producers. Thus, the Consortium is requesting three years of exemption.

2006	<u>495,800</u>	<u>lbs.</u>	Area Treated	<u>3,700</u>	<u>Acres</u>
2007	<u>529,300</u>	<u>lbs.</u>	Area Treated	<u>3,950</u>	<u>Acres</u>

Place an "X" in the column(s) labeled "Not Technically Feasible" and/or "Not Economically Feasible" where appropriate. Use the "Reasons" column to describe why the potential alternative is not feasible.

Potential Alternatives	Not Technically Feasible	Not Economically Feasible	Reasons
Metam-Na	X		This potential alternative has an extended time between application and crop planting (compared to methyl bromide) and is not very effective on nutsedge.
chloropicrin	X		This alternative does not give effective control of nutsedge.
1,3-D	X		This alternative does not give effective control of nutsedge. Problem with 1,3-D phytotoxicity in early spring planting.
1,3-D, chloropicrin	X		This alternative does not give effective control of nutsedge. Problem with 1,3-D phytotoxicity in early spring planting.
1,3-D, brush burning	X		This alternative does not give effective control of nutsedge. Problem with 1,3-D phytotoxicity in early spring planting.
1,3-D, chloropicrin, metam-Na	X		This alternative does not give effective control of nutsedge. Problem with 1,3-D phytotoxicity in early spring planting.
1,3-D, chloropicrin, pebulate	X		This alternative gives good control of nutsedge or nightshade, but is not registered on peppers. Problem with 1,3-D phytotoxicity in early spring planting.
1,3-D, metam-Na	X		This alternative does not give effective control of nutsedge. Problem with 1,3-D phytotoxicity in early spring planting.
metam-Na, chloropicrin	X		This alternative does not give effective control of nutsedge
metam-Na, crop rotation	X		This alternative does not give effective control of nutsedge
metam-Na, solarization	X		This alternative does not give effective control of nutsedge
solarization, fungicides	X		This alternative does not give effective control of nutsedge

Summary – The Need for Methyl Bromide in Vegetable Crops

David Monks

Extension Weed Specialist – Small Fruits and Vegetable Crops

Department of Horticultural Science

North Carolina State University

And

Frank Louws

Department of Plant Pathology

North Carolina State University

Yellow and purple nutsedge are major problems in many crops grown in the southeastern U.S. (D.W. Monks, J.R. Schultheis, D.C. Sanders, S. Culpepper, W.M. Stall, J. Byrd - personal communication; Morales-Payan et al - see appendix; Sorensen et al - see appendix).

It has been demonstrated that nutsedges have a detrimental effect on vegetable crops (Morales-Payan et al - see appendix). The importance of early season weed control in high value crops such as pepper, tomato, and cucurbit crops has also been shown. For example, Frank et al (see appendix) reported that weeds in pepper for 40 to 60 days could reduce yield by 10 to 50%. Stall and Morales-Payan (see appendix) reported that tomato must be nutsedge-free for between 2 to 10 weeks to keep yield reductions below 5%. Mallet and Ashley (see appendix) reported squash must remain near weed free in weeks 4 to 6 to maintain optimum yield and quality. For cucumbers, it has been shown that this crop must remain near weed free from 12 to 36 days after emergence to prevent yield reductions (Friesen - see appendix). Cantaloupe must be kept near weed free for 6 weeks to prevent yield and quality reductions (Nerson - see appendix).

In many agronomic crops there are herbicides that give effective control. However, many vegetable crops do not have effective herbicides that will control both yellow and purple nutsedge - common weeds in the southeastern U.S. (North Carolina Agricultural Chemical manual - see appendix). Among the vegetable crops which do not have herbicides which control yellow and purple nutsedge are pepper, and some of the cucurbit crops. Tillam herbicide in tomato controls both yellow and purple nutsedge but it causes crop injury in the southeastern U.S. [S. Culpepper (Georgia) - see appendix; D.W. Monks (North Carolina) (personal communication)]. Currently, yellow and purple nutsedge are controlled by methyl bromide in crops which are listed on the methyl bromide label. In the past, yellow nutsedge was the primary nutsedge in crops grown in the southeastern U.S. However, currently purple nutsedge has become as common as yellow nutsedge in these crops. Thus, yellow and purple nutsedge infest much of the prime cropland in the southeastern U.S. where these specialized (strawberries and vegetable crops) are grown. Much of cropland in the southeastern U.S. is rotated to and from various vegetable crops and strawberries. Methyl bromide continues to be an important factor in controlling nutsedge in these crops. It is critical for growers to

attempt to eliminate nutsedge from these fields since even a single nutsedge plant is capable of producing 140 shoots (yellow) or 280 shoots (purple) in 6 months (Webster -- see appendix) which leads to re-infestation. Each shoot is associated with one tuber. With the loss of methyl bromide which is currently giving excellent control of these pests, an increase in nutsedge in these crops is anticipated for at the following reasons.

*With the methyl bromide alternative fumigants (metam-Na, 1,3-D, chloropicrin), longer preplant periods will be needed for fumigant dissipation and to prevent injury to crops especially under wet and/or cool conditions (see labels in appendix). Thus, it is likely that fumigant application under plastic will occur earlier in the when temperatures are cooler. These growing conditions and the favorable soil conditions (fertility, etc) will stimulate nutsedge tuber germination and growth. Thus, it is feasible that nutsedge will establish in early summer even prior to planting some crops. Once established, nutsedge will easily compete with young susceptible crop plants causing reduced crop growth and size, and ultimately reduced winter survival and yield by competing with young crop for light, moisture and nutrients.

*There are no herbicides which control nutsedge in the crop row (refer to labels of herbicides labeled for pepper, cucurbit crops). Boar or Gramoxone (paraquat) and Roundup (not tomato) (this glyphosate registration was developed through the IR-4 program) are registered in these crops and will suppress emerged nutsedge but can not be used in the crop row because these herbicides will injure the crop. These herbicides can only be used in the row middles between crop rows. Crop selectivity is based on keeping these herbicides from contacting the crop.

*Methyl bromide is currently providing control of nutsedge and once phased out fumigant replacements (chloropicrin products -- Telone II, Telone C-17, Telone C-35) will not provide consistent effective control of nutsedge. In fact, their labels support this fact because weed control is not claimed on the labels of these fumigants (see appendix). In addition, the label for Metam-Na only claims nutsedge suppression and not control, and the label indicates that nutsedge tubers often remain viable and at a later time will regrow. Research across all crops (strawberry, cucurbit crops, tomato, pepper) and listed in Tables 3-A through 3-D also indicate that methyl bromide is more consistent and more effective in controlling nutsedge than any of the other possible fumigants.

*Cultivation and/or hand removal is not an option because of the many shoots of nutsedge (yellow and purple) results in high densities of infestations. Removal of high densities of nutsedge would be very time consuming, very costly and ineffective since nutsedge could regenerate easily from rhizome or nutlets. This regeneration would demand that growers make hand remove multiple times. I estimate that two to three removals would be necessary and with this intense management costs would likely be over \$2000 per acre. Vegetable production on plastic does not allow for any mechanical cultivation as it would be destructive to the plastic mulch.

Current and future research in vegetable crops -- Herbicides which have broad spectrum activity on weeds are being evaluated in vegetable crops to provide improved weed

control including nutsedge control over the methyl bromide alternative fumigants alone. Some of these herbicides are effective in controlling nutsedge. However, whether they are safe to strawberries will be determined. Sulfentrazone, carfentrazone, halosulfuron, metolachlor, dimethenamid, and bentazon, are among the herbicides being evaluated.

Whereas effective weed control is a driving force limiting the utility of alternative fumigants, we have encountered other issues related to some of the alternatives.

We have conducted multiple trials in vegetable production systems (see appendix, List of trials and Table 3A-3D in the tomato CUE). In most cases, these trials have been conducted in the later spring or early summer when soil temperatures have increased. However, in our tomato work in particular, early season application of Telone or products that contain a portion of Telone has led to phytotoxicity (plant stunting in particular) even when a 21 day waiting period was honored. More work is required to learn how the Telone component can be incorporated in our management systems to manage nematodes but avoid phytotoxicity for our early season crops. We have plans to conduct this work (see appendix) but may not have sound recommendations by 2005.

We have done some work with metam sodium in vegetable production systems. It is weak to moderate in managing Verticillium wilt (race 2) in tomatoes. More importantly, results by different research personnel and growers has been erratic. We believe erratic results in part are due to improper land preparation and application technologies and methods (soil moisture, distribution in soil profile etc). In our work, we have had good success with strawberries, weak to moderate success in tomatoes, and virtually no work in pepper production systems. More research is needed with this product and more time is needed for our growers to learn how to use it with optimum efficacy. We are also beginning to do more work using reduced rates of metam sodium in combination with other fumigants to complement the weak links of each product (weed vs. disease control).

Review of Alternatives

The original information in the following summary was in the University of Georgia's CEU and was edited to fit our CEU package. The term "vegetables" in the following summary, in most cases, refers to pepper, tomato, cucurbit crops and strawberries.

Alternative 1. Tillage

Cyperus species are the most common and troublesome weeds of vegetable crops in the southeastern U.S. [D. W. Monks 2002 (personal communication), Webster 2002]. While tillage/cultivation may be an effective means of reducing annual weed populations (Bellinder et al. 2002; Amador-Ramirez 2001), any activity that eliminates *Cyperus* species foliage will have only marginal success. Removal of sprouts from the first flush of *Cyperus esculentus* was successful in reducing the subsequent shoot populations by 50% at two weeks after treatment (Thullen and Keeley 1975). However, shoot populations rebounded to within 90% of pretreatment levels by eight weeks after treatment (Thullen and Keeley 1975). In fact, tillage operations have been shown to be deleterious to the management *Cyperus* species. Tillage will break rhizome chains, releasing dormant tubers from the restrictions of apical dominance and thereby increasing the shoot population. Also, tillage will move tubers away from the parent plant, reducing the intraspecific competition among *Cyperus* species and allowing these weeds to colonize new areas. Schippers et al. (1993) noted that farming operations were the main cause of dispersal of *Cyperus* species in the field. Tillage caused a threefold increase in *Cyperus esculentus* infestation levels compared to a no-tillage situation. Therefore, tillage should not be considered a viable alternative for methyl bromide in control of *Cyperus* species in vegetable production.

Secondary tillage operations such as cultivation or plowing have also been shown to have minimal impact on controlling *Cyperus* species. Webster and Coble (1997) noted that there were 323 *Cyperus rotundus* per meter in the non-treated control during a 1994 study. Cultivating had little impact managing this weed in their trial as the cultivated treatment contained over 258 plants per meter square at seasons end. Similarly, in 1995 *Cyperus rotundus* populations were reduced only 25% compared to the non-treated control (Webster and Coble 1997). In addition, secondary implements such as cultivating do not provide control of weeds in the row where interspecific (*Cyperus* species-crop) competition and yield loss are most severe. Secondary tillage is not possible in most vegetable crops produced using plastic mulch since it will damage or destroy the mulch.

Hand removal (hoeing) is also used in vegetable crops to control weeds. However, for the same reasons that cultivation does not control weeds, hand removal will not effectively control *Cyperus* species, and hand removal would be extremely labor intensive, time consuming and cost prohibitive because *Cyperus* levels can reach as high or higher than 258 plants per meter have been reported (Webster and Coble 1997), requiring individual removal of each shoot.

Amador-Ramirez, M. D., R. G. Wilson, and A. R. Martin. 2001. Weed control and dry bean (*Phaseolus vulgaris*) response to in-row cultivation, rotary hoeing, and herbicides. Weed Tech. 15:429-436.

- Bellinder, R. R., J. J. Kirkwyland, R. W. Wallace, and J. B. Colquhoun. 2000. Weed control and potato (*Solanum tuberosum*) yield with banded herbicides and cultivation. *Weed Tech.* 14:30-35.
- Buhler, D. D., D. E. Stoltenber, R. L. Becker, and J. L. Gunsolus. 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. *Weed Sci.* 42:205-209.
- Schippers, P., S. J. Ter Borg, J. M. Van Groenendael, and B. Habekotte. 1993. What makes *Cyperus esculentus* (yellow nutsedge) an invasive species? – a spatial model approach. Brighton Crop Protection Conference – Weeds. Pp. 495-504.
- Thullen, R. J. and P. E. Keeley. 1975. Yellow nutsedge sprouting and respouting potential. *Weed Sci.* 23: 333-337.
- Webster, T. M. and H. D. Coble. 1997. Purple nutsedge (*Cyperus rotundus*) management in corn (*Zea mays*) and cotton (*Gossypium hirsutum*) rotations. *Weed Tech.* 11:543-548.

Alternative 2: 1,3-D; 9 to 25 gallons Telone II per acre

1,3-D has little to no activity on the control of weed species, including *Cyperus* species (Noling et al. 2000, Melichar et al. 1995, Roskopf et al. 1999, Webster et al. 2001). In contrast, methyl bromide effectively and consistently controls many weedy pests including *Cyperus* species (Culpepper and Langston 2001, 2002; Locascio et al. 1995; Locascio et al. 1997; Locascio and Dickson 1998; Nelson et al. 1999; Noling et al. 2000; Unruh et al. 2002). Therefore, 1,3-D will not be an effective alternative to methyl bromide for the control of *Cyperus* species.

- Culpepper, A.S. and D. L. Langston. 2001. Pepper and nutsedge response to fumigant/herbicide combinations. University of Georgia, Tifton, GA. Unpublished, data included
- Culpepper, A.S. and D. L. Langston. 2002. Tomato and nutsedge response to fumigant/herbicide combinations. University of Georgia, Tifton, GA. Unpublished, data included.
- Locascio, S. J. and D. W. Dickson. 1998. Metam sodium combined with chlorpicrin as an alternative to methyl bromide. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Locascio, S. J., D. W. Dickson, and T. A. Kucharek. 1995. Fumigant alternative to methyl bromide for polyethylene mulched tomato. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Locascio, S. J., J. P. Gilreath, D. W. Dickson, T. A. Kucharek, J. P. Jones, and J. W. Noling. 1997. Fumigant alternatives to methyl bromide for polyethylene-mulched tomato. *Hortsci.* 32(7):1208-1211.
- Locascio, S. J., J. P. Gilreath, D. W. Dickson, T. A. Kucharek, J. P. Jones, and J. W. Noling. 1997. Pest control with alternative fumigants to methyl bromide for tomato. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Melichar, M. W., J. E. Eger, R. M. Huckaba, J. P. Mueller, and L. G. Peterson. 1995. Soil injection of 1,3-dichloropropene, alone or combined with chloropicrin and/or preemergent herbicides, for nematode, soil-borne disease and weed control. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Nelson, S. D., S. J. Locascio, L. H. Allen, Jr., D. W. Dickson, and D. J. Mitchell. 1999. Soil flooding and chemical alternatives to methyl bromide in tomato production. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>

- Noling, J. W., E. Roskopf, and D. L. Chellemi. 2000. Impacts of alternative fumigants on soil pest control and tomato yield. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Roskopf, E. N., D. O. Chellemi, and N. Kokalis-Burelle. 1999. Alternative soil disinfestations treatments for weed control. Impacts of alternative fumigants on soil pest control and tomato yield. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Unruh, J. B., B. J. Brecke, J. A. Dusky, and J. S. Godbehere. 2002. Fumigant alternatives for methyl bromide prior to turfgrass establishment. *Weed Technol.* 16:379-387.
- Webster, T.M., A.S. Csinos, A.W. Johnson, C.C. Dowler, D.R. Summer and R.L. Fery. 2001. Methyl bromide alternatives in a bell pepper-squash rotation. *Crop Protection* 20:605-614.

Alternative 3. Chloropicrin; 390 kg per hectare

Very few scientific based studies have evaluated chloropicrin applied alone as a methyl bromide alternative in Southeastern vegetable production. Work with chloropicrin has predominately been the application of 1,3-D plus chloropicrin (Culpepper and Langston 2001, 2002; Locascio et al. 1997; Melichar et al. 1995; Noling et al. 2000; Roskopf et al. 1999). As previously mentioned, the commercial use rates of 1,3-D plus chloropicrin do not appear to be a valid methyl bromide alternative. Locascio et al. (1997, 1999) applied commercial use rates of chloropicrin comparing *Cyperus* control to methyl bromide and the non-treated control. In their Florida studies, chloropicrin applied alone had little to no activity in controlling *Cyperus* as the number of plants per square meter were statistically similar to the non-treated control. In the same trial, methyl bromide provided 77 to 93% *Cyperus* control. In other studies, chloropicrin increased *Cyperus* emergence (Motis and Gilreath 2002). More research data is needed evaluating chloropicrin application timings in Southeast vegetable production. This work is in progress and will continue in southeastern U.S. [Culpepper and Langston 2001, 2002; Monks (personal communication) 2002]. However, at this time, chloropicrin is not a valid alternative to methyl bromide for the control of *Cyperus* species.

- Culpepper, A.S. and D. L. Langston. 2001. Pepper and nutsedge response to fumigant/herbicide combinations. University of Georgia, Tifton, GA. Unpublished, data included
- Culpepper, A.S. and D. L. Langston. 2002. Tomato and nutsedge response to fumigant/herbicide combinations. University of Georgia, Tifton, GA. Unpublished, data included.
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- Locascio, S.J., S.M. Olson, C.A. Chase, T.R. Sinclair, D.W. Dickson, D.J. Mitchell, and D.O. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Melichar, M. W., J. E. Eger, R. M. Huckaba, J. P. Mueller, and L. G. Peterson. 1995. Soil injection of 1,3-dichloropropene, alone or combined with chloropicrin and/or preemergent herbicides, for nematode, soil-borne disease and weed control. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Motis, T.N. and J.P. Gilreath. 2002. Stimulation of nutsedge emergence with chloropicrin. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Nelson, S. D., S. J. Locascio, L. H. Allen, Jr., D. W. Dickson, and D. J. Mitchell. 1999. Soil flooding and chemical alternatives to methyl bromide in tomato production. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Noling, J. W., E. Roskopf, and D. L. Chellemi. 2000. Impacts of alternative fumigants on soil pest control and tomato yield. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Roskopf, E. N., D. O. Chellemi, and N. Kokalis-Burelle. 1999. Alternative soil disinfestations treatments for weed control. Impacts of alternative fumigants on soil pest control and tomato yield. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. <http://www.mbao.org/>
- Unruh, J. B., B. J. Brecke, J. A. Dusky, and J. S. Godbehere. 2002. Fumigant alternatives for methyl bromide prior to turfgrass establishment. *Weed Technol.* 16:379-387.

Alternative 4. 1,3-D plus chloropicrin; Telone C-17 at 11 to 30 gallons per acre, Telone C-35 at 13 to 36 gallons per acre

Methyl bromide effectively and consistently controls many weedy pests including *Cyperus* species (Culpepper and Langston 2001, 2002; Locascio et al. 1995; Locascio et al. 1997; Locascio and Dickson 1998; Nelson et al. 1999; Noling et al. 2000; Unruh et al. 2002). 1,3-D plus chloropicrin has shown activity in suppressing weeds in some studies; however, control of *Cyperus* species is often inadequate and far less effective than methyl bromide (Culpepper and Langston 2001, 2002, Locascio 1999). Locascio et al. (1997) reported statistically similar and numerically higher numbers of *Cyperus* species in plots treated with 1,3-D + 17% chloropicrin as compared to the non-treated check. Methyl bromide, in this same study, provided 77 to 93% *Cyperus* control compared to the non-treated check. Culpepper and Langston (2002), compared two commercial rates of 1,3-D + chloropicrin to methyl bromide. Telone 35 (1,3-D + chloropicrin) at 18 and 35 gallons per acre provided 53% and 80% control of *Cyperus esculentus* at 4 weeks after treatment. In contrast, methyl bromide provided complete *Cyperus esculentus* control throughout the study. Similar to 1,3-D applied alone, the mixture of 1,3-D plus chloropicrin may adequately control many pests but this fumigant combination is not as effective as methyl bromide for the control of *Cyperus* species in Southeastern vegetable production.

- Culpepper, A.S. and D. L. Langston. 2001. Pepper and nutsedge response to fumigant/herbicide combinations. University of Georgia, Tifton, GA. Unpublished, data included
- Culpepper, A.S. and D. L. Langston. 2002. Tomato and nutsedge response to fumigant/herbicide combinations. University of Georgia, Tifton, GA. Unpublished, data included.

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Alternatives 5: Metam sodium; 37.5 to 50 gallons per acre

Methyl bromide effectively and consistently controls many pests including *Cyperus* species (Culpepper and Langston 2001, 2002; Locascio et al. 1995; Locascio et al. 1997; Locascio and Dickson 1998; Locascio et al. 1999; Nelson et al. 1999; Noling et al. 2002; Unruh et al. 2002). Metam sodium is consistently ineffective in controlling *Cyperus* species (Culpepper and Langston 2001, 2002; Locascio et al. 1995; Locascio et al. 1997; Locascio and Dickson 1998; Nelson et al. 1999; Noling et al. 2000; Unruh et al. 2002). Dowler (1999) indicated that metam applied through drip irrigation under a plastic mulch controlled *Cyperus* species 80-90% in a 23 cm band on either side of the drop tape line. However, *Cyperus* species remained on the shoulder or edge of the plastic bed. Research determined that a single *Cyperus* species tuber was capable of expanding into a patch of 7.85 m² (84 ft²) in a single growing season (Webster 2002). This indicates

that even a low population of tubers of *Cyperus* species have the potential to quickly reinfest previously treated areas. Commercial rates of metam did not suppress *Cyperus rotundus* relative to the non-treated check by the end of the season for *Capsicum annuum* (bell pepper) produced on plastic (Webster et al. 2001). Methyl bromide was the only material in this study that did suppress *Cyperus rotundus* by the conclusion of the season. Similarly, Unruh et al. (2002) reported unsatisfactory control of *Cyperus* species by fumigants slated as potential alternatives to methyl bromide for turfgrass establishment. Locascio et al. (1997) had no control of nutsedge with metam at two locations when compared to the non-treated control. At the same two locations, methyl bromide reduced nutsedge populations by 77 to 93%. Similarly, Locascio and Dickson (1998) reported over twice the number of nutsedge plants in the metam treated plot compared to the non-treated check while methyl bromide provided at least 85% control of nutsedge compared to the non-treated check. Nelson et al. 1999 did not report a reduction of *Cyperus* species by 45% when applying commercial rates of metam but control was far less than the 93% noted with methyl bromide. In addition, Benlioglu and co-workers (2002) did not observe nutsedge control with metam sodium.

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Alternative 6: Metam sodium and crop rotation

While many studies have demonstrated that cover crops and mulches are effective in reducing weed populations, cover crops and mulches have proven to be unacceptable alternatives to methyl bromide for the control of *Cyperus* species. Burgos and Talbert (1996a) planted rye plus hairy vetch, rye, or wheat as a cover crop to measure their impact on weed control. These cover crops inhibited and reduced early season *Amaranthus retroflexus* (redroot pigweed) and *Digitaria sanguinalis* (large crabgrass) growth by 50%. While this was a promising result, none of the cover crops reduced the population of *Cyperus esculentus* (yellow nutsedge) (Burgos and Talbert 1996a). In some instances, the cover crops that were most effective in reducing weed growth also delayed crop maturity and reduced crop emergence, height, and yield (Burgos and Talbert 1996a, 1996b; Galloway and Weston 1996). Therefore, research to date does not support the likelihood that cover crops are an adequate replacement for methyl bromide in the control of *Cyperus* species. Additionally, mulching has not been effective for nutsedge control (William, 1976), because nutsedge will penetrate organic or physical mulches (Chase et al. 1998; Patterson 1998).

Additional concerns with cover crops are the unknown impacts of allelochemicals. Allelochemicals are the compounds that are released by living cover crop or decaying cover crop residue that negatively affect the growth of the cash crop. Allelochemicals from rye have been shown to be phytotoxic to corn (Johnson et al. 1993). A similar study demonstrated that wild radish residue has the potential to injure many crops including cotton (Norsworthy, Clemson University; unpublished data). Another study found that residues from *Apium graveolens* (celery) reduced growth of some small seeded broadleaf weeds [*Raphanus sativus* (wild radish) and *Portulaca oleracea* (common purslane)]. However, none of these studies evaluated the effects of allelochemicals on *Cyperus* species. Most of the species that were affected by the

allelochemicals were small-seeded that possess, relative to *Cyperus* species, a small carbohydrate (energy) source.

Methyl bromide effectively and consistently controls many pests including *Cyperus* species (Culpepper and Langston 2001, 2002; Locascio et al. 1995; Locascio et al. 1997; Locascio and Dickson 1998; Nelson et al. 1999; Noling et al. 2000; Unruh et al. 2002). Metam sodium is consistently ineffective in controlling *Cyperus* species (Culpepper and Langston 2001, 2002; Locascio et al. 1995; Locascio et al. 1997; Locascio and Dickson 1998; Nelson et al. 1999; Noling et al. 2000; Unruh et al. 2002). Dowler (1999) indicated that metam applied through drop irrigation under a plastic mulch controlled *Cyperus* species 80-90% in a 23 cm band on either side of the drip tape line. However, *Cyperus* species remained on the shoulder or edge of the plastic bed. Research determined that a single *Cyperus* species tuber was capable of expanding into a patch of 7.85 m² (84 ft²) in a single growing season (Webster 2002). This indicates that even a low population of tubers of *Cyperus* species have the potential to quickly reinfest previously treated areas. Commercial rates of metam did not suppress *Cyperus rotundus* relative to the non-treated check by the end of the season for *Capsicum annuum* (bell pepper) produced on plastic (Webster et al. 2001). Methyl bromide was the only material in this study that did suppress *Cyperus rotundus* by the conclusion of the season. Similarly, Unruh et al. (2002) reported unsatisfactory control of *Cyperus* species by fumigants slated as potential alternatives to methyl bromide for turfgrass establishment. Locascio et al. (1997) had no control of nutsedge with metam at two locations when compared to the non-treated control. At the same two locations, methyl bromide reduced nutsedge populations by 77 to 93%. Similarly, Locascio and Dickson (1998) reported over twice the number of nutsedge plants in the metam treated plot compared to the non-treated check while methyl bromide provided at least 85% control of nutsedge compared to the non-treated check. Nelson et al. 1999 did not report a reduction of *Cyperus* species by 45% when applying commercial rates of metam but control was far less than the 93% noted with methyl bromide.

Neither metam nor cover crops are consistently effective in managing *Cyperus* species. Therefore, a systems approach utilizing both metam and crop rotation would likely be as unsuccessful as either management tactic alone. No study has indicated success managing *Cyperus* species when utilizing both metam and crop rotation, especially when compared to the consistent control noted with methyl bromide. In addition, several studies as cited below have shown metam and crop rotation are not valid alternatives to methyl bromide for the control of *Cyperus* species.

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- Chase, C. A., T. R. Sinclair, D. G. Shilling, J. P. Gilreath and S. J. Locascio. 1998. Light effects on rhizome morphogenesis in nutsedge (*Cyperus* spp): implications for control by soil solarization. *Weed Sci.* 46: 575-580.
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Alternatives 7: Biological Control

Several pathogens have been evaluated in the field and greenhouse for biological control of *Cyperus* species (Kadir et al. 2000, Phatak et al. 1983). Kadir et al. (2000) noted that an isolate of the fungus *Dactylaria higginsii* obtained from *Cyperus rotundus* in Florida was pathogenic to *Cyperus* species. In their study, two inoculations at 10^6 conidia/ml reduced *Cyperus rotundus* shoot dry weight 74%, tuber numbers 71%, and weight per tuber 45%. A third inoculation with 10^6 conidia/ml did not significantly reduce growth compared to plants inoculated twice. Although Kadir et al. (2000) noted suppression of tuber production by this fungus, another study by Kadir and Charudattan (1999) noted the same fungus "did not kill nutsedge bulbs or tubers, but reduced shoot and tuber yields".

Phatak et al. (1983) has also studied the impact of *Puccinia canaliculata* (rust) for the control of *Cyperus esculentus*. Phatak et al. (1983) applied *Puccinia canaliculata* 66%, and completely inhibited flowering.

Cyperus control at a level accomplished by Phatak et al. (1983) or Kadir et al. (2000) would not be acceptable for the management of *Cyperus* species to reproduce. Research from Georgia (Webster et al. 2002) indicates that a single *Cyperus* species to reproduce. Research from 29 shoots in the matter of three months and over 323 shoots in six months. In addition, this indicates that *Cyperus* species will begin to recolonize from areas that are not infested with very high quantities of a fungus (Kadir et al. 2000). Although, Phatak et al. (1983) noted complete control of *Cyperus esculentus* seedheads by *Puccinia canaliculata*, less than 1% of seeds produced from seedheads germinate and survive to become a mature plant as reproduction is primarily through tuber production (Webster 2002).

To date, there are no bioherbicides registered or available for management of *Cyperus* species in Georgia vegetable crops. There are several biological agents in nature that reduced *Cyperus* species development (Phatak et al. 1983), but these agents occur too sporadically and have had problems when integrated into production systems (Beste et al. 1992). Therefore, the use of biological control as a methyl bromide alternative is not feasible for the S.E. U.S. vegetable producer.

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- Kadir, J. B. and R. Charudattan. 1999. Occurrence of *Dactylaria higginsii* on purple nutsedge in Florida. *Plant Disease* 83: 588.
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- Webster, T. M. 2002. Nutsedge (*Cyperus* spp.) Eradication: Impossible Dream? In: Riley, L.E.; Dumroese, R. K.; Landis, T. D. (Compilers). 2002. National Nursery Proceedings 2002. Proceedings RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Alternate 8: Biofumigation

Biofumigation is the amendment of soil with organic matter which releases gases that eliminate or control pest. An example of biofumigation for weed management would be the incorporation of some *Brassica* species and various *Compositae* into the soil. As these plant species decompose they give off volatile chemicals such as methyl

isothiocyanate and phenethylisothiocyanate which have herbicidal properties according to the UNEP committee report referencing work by Gamliel and Stapleton (1997).

Unfortunately in the Gamliel and Stapleton (1997) article, they do not provide any weed control data from their study with *Brassica* species. although no data was available in Gamliel and Stapleton (1997), Bewick et al. (1994) noted that residues from *Apium graveolens* (celery) reduced growth of some small seeded broadleaf weeds including *Raphanus sativus* (wild radish) and *Portulaca oleracea* (common purslane). Most of the species that were affected by the allelochemicals were small-seeded species that possess, relative to *Cyperus* species, a small carbohydrate (energy) source.

In addition to the lack of scientific data for the activity of biofumigation on *Cyperus* species, there is concern from several studies suggesting biofumigant weed management systems may release allelochemicals that can be phytotoxic to the crop being produced. For example, wild radish, a *Brassica* species, has been shown to be highly phytotoxic to many crops including cotton (Norsworthy 2002). Johnson et al. (1993) also showed that rye was phytotoxic to corn due to allelochemical releases from the rye. It is likely that these allelochemicals are toxic to many vegetable crops and, thus, a great need for research is needed prior to considering biofumigation as a practical replacement for methyl bromide in the control of *Cyperus* species.

- Bewick, T. A., D. G. Shilling, J. A. Dusky, and D. Williams. 1994. Effects of celery (*Apium graveolens*) root residue on growth of various crops and weeds. *Weed Technol.* 8: 625-629.
- Gamliel, A. and J. J. Stapleton. 1993. Characterization of antifungal volatile compounds evolved from solarized soil amended with cabbage residues. *The American Phytopathological Soc.* Vol. 83, No. 9, 1993. pp. 899-905.
- Johnson, G. A., M. S. Defelice, and A. R. Helsel. 1993. Cover crop management and weed control in corn (*Zea mays*). *Weed Technol.* 7: 425-430.
- Norsworthy, J. 2002. Allelopathic affects of wild radish on cotton. Clemson University. Unpublished, data included.

Alternative 9: Solarization

Soil solarization has been an effective replacement for methyl bromide for the management of several pests with the exception of *Cyperus* species. The literature is scattered with vague references to the effectiveness of the solarization for the management of *Cyperus* species, but it quickly becomes apparent the response of *Cyperus* species to solarization is sporadic and not well understood. While some data indicates solarization can be a beneficial alternative to methyl bromide (Chellemi et al. 1997; Ricci et al. 1999; Ricci et al. 2000; Stevens et al. 1990), other studies have found solarization to provide, at best, suppression of populations of *Cyperus* species (Chase et al. 1998; Egley 1983; Standifer et al. 1984). Other researchers (Gilreath et al 1999; Locascio et al 1999, Benlioglu et al 2002) have found solarization to have no effect on *Cyperus* species.

Stevens et al. (1990) reported that soil solarization reduced *Cyperus rotundus* populations 87% in collard greens. However, a population of greater than 22 *Cyperus rotundus* plants per square meter remained following this treatment, a population that will compete with crops for water and nutrients. Solarization for one week during mid summer provided good control of several weeds including *Sida spinosa* (prickly sida) and *Anoda cristata* (spurred annoda) (Egley 1983). However, solarization was found to

stimulate emergence of *Cyperus rotundus* (Egley 1983). These results were confirmed in a subsequent study where solarization increased *Cyperus rotundus* sprouting 3 to 23% (Miles et al. 2002). Solarization for 210 days with transparent polyethylene sheets reduced *Cyperus rotundus* populations 59% (Ricci et al. 1999; Ricci et al. 2000). Temperatures within the top 10 cm of the soil profile were increased 23% relative to the non-solarized control. Chellemi et al. (1997) attributed the observed nutsedge suppression to the acts of solarization, however temperatures in the study did not approach those necessary for solarization (Patterson 1998).

Chase et al. (1999) compared the effect of maximum soil temperatures (40, 45, 50, and 55 C) to determine the lethal temperature for *Cyperus* species. Temperatures above 50 C were lethal to tubers, however maintaining this soil temperature throughout the soil profile where nutsedge germinates is not currently feasible. In Tifton, GA during February when solarization would be needed for the spring crop, soil temperatures are only 14 and 15 degrees C at 5 and 10 cm, respectively (GCPES 2002). C. Miles et al. (2002) reported that soil temperatures with solarization increased only 5.8 degrees C after a 5-week period in the spring. Therefore, soil temperatures with spring solarization in Georgia would reach only on average only 20.8 C degrees at a 5 cm depth, far less than the 50 to 55 degrees needed to eliminate nutsedge as noted by Chase et al. (1999). In much of the Southeastern U.S., especially in the northern fringe states of North Carolina and Tennessee, soil temperatures would be cooler than those temperatures in Tifton, GA. Similarly, in mid summer the average soil temperature for Tifton is 36 and 31 degrees C at 5 and 10 cm, respectively (GCPES 2002). Soil temperatures in mid summer were raised 7.2 C after five weeks of solarization in Hawaii (Miles et al. 2002). Again, in mid summer Georgia soils would reach at most 43.2 degrees C at 5 cm and at most 38.2 degrees C at 10 cm, far less than the 50 to 55 degrees C needed for an acceptable nutsedge management approach.

Field studies indicated that summer solarization only suppressed *Cyperus rotundus* populations (Chase et al. 1998). Other research demonstrated that solarization was effective in reducing weed propagule populations (including tubers of *Cyperus* species) within a shallow portion of the soil profile (Standifer et al. 1984). Solarization using translucent and black polyethylene mulches for up to 12 weeks eliminated tubers of *Cyperus* species in the upper 3 to 4 cm of the soil. Only 45% of *Cyperus rotundus* were found to be distributed in the top 4 cm of the soil profile (Siriwardana and Nishimoto 1987). The large carbohydrate reserves of the tubers of the *Cyperus* species allow them to emerge from depths in the soil profiles below this treated zone. Research from Georgia (Webster et al. 2002) indicates that a single purple nutsedge tuber will produce 29 shoots in the matter of three months and over 323 shoots in six months. In addition, this indicates that nutsedge will begin to recolonize from areas that are not affected by solarization.

In summary, studies have demonstrated that a temperature of 65 C for 30 minutes will eliminate many economically important soil-borne plant pathogenic fungi, nematodes, insects, and weeds (Pullman et al. 1981). However, several essential issues may restrict the utility of this treatment for management of *Cyperus* species. First, raising soil temperatures to levels required for solarization to be effective in eliminating tuber viability is exceedingly difficult. Even with the most technologically advance polyethylene mulches, soil temperatures can be increased 7.7 C at 5 cm and 3.6 C at 25

cm (Chase et al. 1999). The effect of this heating effect quickly dissipates as soil depth increases, potentially leaving many tubers nontreated. Second, tuber of *Cyperus* species have the ability to emerge from relatively large depths in the soil profile due to their large carbohydrate (energy) reserves. Given a best case scenario of an effective solarization treatment, tubers would still be distributed out of the zone of solarization, allowing *Cyperus* species to quickly reinfest previously treated areas. Finally, the relationship between soil temperature and duration of exposure has not been established for *Cyperus* spp., therefore it is unclear how high soil temperatures need to be elevated and for how long they need to remain at these levels.

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Alternative 10: Rotation

Rotation is an effective tool to assist in the management of weeds, disease, and nematodes in all crops. However, the possibility of rotation successfully replacing methyl bromide for the control of nutsedge is not likely in S.E. U.S. vegetable production. The premise of crop rotation is to introduce crops with different planting and harvest dates, various crop competitive characteristics, and unique weed control options. However, as nutsedge shoots emerge from tubers with large energy reserves, these species may be more resistant to the effects of planting dates and crop season length. Annual weeds are often more susceptible to those types of control, as the energy resources are limited relative to those in the tubers of *Cyperus* species. Also, while many annual weed species do not produce seed until the end of their growing cycle (which allows for the disruption in their life cycle with cropping systems of different lengths), *Cyperus* species can produce tubers six to eight weeks after foliar emergence.

Johnson and Mullinix (1997) showed that uninterrupted plantings of *Arachis hypogea* (peanut), *Gossypium hirsutum* (cotton), or *Zea mays* (corn) with moderate levels of weed management including an arsenal of herbicides suppressed *Cyperus esculentus* (yellow nutsedge) development. Although rotation can be fairly effective in agronomic crops, these management tactics are less effective in vegetable crops. Agronomic crops (e.g. *Zea mays* and *Gossypium hirsutum*) are often more competitive with nutsedge relative to most slow growing vegetable crops. Additionally, there are several effective herbicide options for *Cyperus* species management in each of the agronomic crops in the *Arachis hypogea* – *Gossypium hirsutum* – *Zea mays* rotation (Johnson and Mullinix 1997). In vegetable crops where methyl bromide has been widely utilized, herbicide options are often nonexistent. As of May 2002, there are no herbicides registered for use in *Cucumis melo* (cantaloupe), *Cucumis sativus* (cucumber), or *Cucurbita pepo* (squash) that will effectively control *Cyperus* species (Culpepper, 2002). Additionally, these cucurbit species are usually rotated with crops in which there are no herbicides that will control *Cyperus* species as of May 2002. One of the benefits of crop rotation is to address problem weeds in crops where herbicide options exist (e.g. halosulfuron in *Zea mays*; imazethapyr and imazapic in *Arachis hypogaea*). However, a side effect of this management system is the potential risk of vegetable crop injury from the persistence of these herbicides in the soil in the season following their application, as indicated on the registration of these particular herbicides.

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(revised August 8, 2003)

Worksheet 4. Future Research Plans

Please describe future plans to test alternatives to methyl bromide. You may use this worksheet to describe all future plans.

1. Identify the top 3 to 5 target pests for your research.

1	Root knot nematode	4	Southern stem rot (<i>Sclerotium rolfsii</i>)
2	Pythium root rot	5	
3	summer annual weeds (crabgrass, nutsedge)		

2. Provide a list of alternative chemicals or cultural practices that have been tested.

1	Telone-C35	4	Herbicides for improved weed management
2	Metam sodium	5	
3	composts		

3. Prioritize the alternative chemicals or cultural practices to be tested.

1	Telone-C35	4	
2	metam sodium	5	
3	composts		

4. What would be the best currently available alternative if methyl bromide were not available?

Choice is site- and pest problem-dependent. For sites with severe problems with nematodes, TC35 will likely be the best approach.

5. Please provide an overview/timeline of the plan to transition away from using methyl bromide.

Research seeking to evaluate alternatives to methyl bromide for pepper pest management began in 1998. Phase I of the research was the conduct of replicated research trials to evaluate alternatives to MB. Phase II (currently underway) extends the information gathered to on-farm trials while continuing to evaluate new methods, products and approaches to implementation.

See attached Clinton Compost Trial 2003 Study Plan

6. Will yield/quality loss be measured?

Yes ☒ No ☐

7. Will economic impacts be measured?

Yes ☒ No ☐

8. How will you minimize your use and/or emissions of methyl bromide?

- (check all that apply)
- ☐ Formulation Changes (please specify)
 - ☐ Tarpeulin (High Density Polyethylene)
 - ☐ Virtually Impermeable Film (VIF)
 - ☐ Other
 - ☐ Cultural Practices (please specify)
 - ☒ Other Pesticides (telone-c35, metam sodium, nui)
 - ☒ Non-Chemical Methods (several compost sources)

Formulation Changes

From: _____ % methyl bromide, _____ % chloropicrin
 To: _____ % methyl bromide, _____ % chloropicrin

9. What is the cumulative amount spent and the types of contributions this consortium has made to fund research to develop alternatives to methyl bromide since 1992? (e.g. consortium dues, direct research funding, etc.)

Years	Name of Organization / Research Institution (FOR ALL COMMODITIES)	Amount (\$)
2000-2002	USDA-Methyl Bromide Alternatives Grant	\$269,018
2002-2004	USDA-Methyl Bromide Alternatives Grant	\$351,854
2000-2003	Industry, Commodity Groups, IR-4 (Estimate)	\$170,000

10. Other total investments, if any, made to reduce your reliance on methyl bromide? \$

(Describe each investment and its associated costs, e.g. specialized machinery, etc.)

Investment (FOR ALL COMMODITIES)	Cost
In-kind Contributions by Growers has been essential (Time, Land, Equipment, Supplies)	
ESTIMATE	\$150,000

11. Grant requests made to USDA, EPA, state, or other funding group. (FOR ALL COMMODITIES)

Local Commodity group requests ongoing (Typically 1-3K per commodity group/yr)

No Pending USDA or EPA proposals

Compost Source Study 2003**Horticultural Crops Research Station, Clinton NC****Test Crops:** Tomato, Pepper, Cucumber**Primary Investigator:** Doug Sanders, Hort. Sci. NCSU**University Cooperators:** Doug Sanders, Kirk Creel, Lisa Ferguson, Frank Louws

Objective: Determine long term (3-5 yrs) influence of compost materials on common vegetable cropping systems. Evaluate composts for disease suppression and nutrient enhancement in a rotation of vegetable crops.

Treatment Codes and Plot Numbers:

Treatment	Rate	Source	Code	Plot Number			
1. Control (untreated)			CK	105	206	306	403
2. Telone-C35	35 gal/A	Dow	TC35	103	201	305	402
3. McGill CMC	20 yd ³ /A	McGill	C1	104	207	308	404
4. McGill CMC + T382	20 yd ³ /A + 2.5 oz inoculum	McGill + Holtink	T382	102	204	301	408
5. CMC + Telone-C35	20 yd ³ /A + 35 gal/A	McGill + Dow	C1-T	101	208	302	407
6. Bio-Comp	20 yd ³ /A	Bio-Comp	C2	106	205	304	406
7. Lexington	20 yd ³ /A	City of Lexington	C3	107	202	303	401
8. Telone-C35 + fertilizer	35 gal/A + CMC N-equivalent	Dow + commercial	TF	108	203	307	405

Replicated Plot Set-up:

The width of the field area is approximately 120' (8 – 15' wide plots across the field) and the length is approx. 150'. Treatments established in 3-row plots 30' long, beds 27" wide (on 5' centers). For 8 treatments to be replicated 4 times = 32 plots x 3 rows = 96 rows. The treated 3-row plots will be used for data collection, such as yield and quality, disease incidence data, soil assays for nutrition and pathogen populations, etc.

Crop: Tomato, Pepper and Cucumber planted in the plots in the spring, followed by squash, cucumber, and cabbage in the fall season, with a vetch/rye cover crop in all plots during the winter season.

Compost Rates: For strawberry work, we have used 20-30 yd³/A rates of controlled microbial compost (CMC) material, usually following a mixed legume-grass cover crop that has been mowed and rotovated into the soil. In vegetable studies, we have used 30 yd³/A of CMC applied only to the bedded area with good results. Very high rates of CMC have been used at Clinton for vegetable production (approx 100 and 200 yd³/A) with some success in pepper, tomato and

cucumber production. Lower rates (20 yd³/A) would be more practical for growers to handle and purchase, as well as amounts that would supply an appropriate volume as a carrier and substrate for T₃₈₂. Broadcast application over all 3 rows followed by tillage will be used to distribute the compost.

Plot layout:

Back of Field

401	402	403	404	405	406	407	408	30 ft length	Row of cypress trees
C3	TC35	CK	C1	TF	C2	C1-T	T382		
Border								10 ft	
301	302	303	304	305	306	307	308	30 ft	
T382	C1-T	C3	C2	TC35	CK	TF	C1		
Border								10 ft	
201	202	203	204	205	206	207	208	30 ft	
TC35	C3	TF	T382	C2	CK	C1	C1-T		
Border								10 ft	
101	102	103	104	105	106	107	108	30 ft	
C1-T	T382	TC35	C1	CK	C2	C3	TF		
15 ft wide	3-row plots								

Front of Field (F-4)

CUE 03-0041

Appendix

2003

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: glyphosate (preplant) [Insert Alternative]

1. Yield Loss & Pest Control When Comparing This Alternative to Methyl Bromide

Provide numerical estimates where possible.

Study # (list below)	Pest Being Tested	% Yield Loss *	% Pest Control *	Details
1	Yellow nutsedge	no crop	29 to 53%	Field and greenhouse studies were conducted with glyphosate (Roundup) to determine its effect on yellow nutsedge tubers and plants. Inadequate control was observed.
2				
3				
4				
5				
Enter Average Loss				

* If no yield or quality loss information is given we will assume no losses. Only provide pest control information if yield or quality loss information is not available.

2. Study Information

For the information in #1 above list: the study name, authors, publication, date, and if a copy is attached.

Study #	Attached?	Details
1	X	Yellow nutsedge control and tuber yield with glyphosate and glufosinate; K.A. Nelson, K.A. Renner and D. Penner; 2002; Weed Technology 16:360-365.
2		
3		
4		
5		

3. Quality Loss *

Describe quality impacts such as: percent smaller fruit, reduced grade, smaller plants, crop damage, disease vector, etc. Refer to market category question in Worksheet 2-C.

Market Category	Yield with Methyl Bromide	Units	Yield With Alternative	Units	Quality Impact Description
Marketable	100%	boxes	50% or less	boxes	Reduction in yield & grade in tomato & pepper & melons & strawberries. Shoots can grow through vegetable fruit (melons) resulting in them being not marketable.

4. Are there any production delays (planting/ harvesting) associated with this alternative?

Yes



No



(If yes, please explain)

Apply approximately 2 to 3 week prior to planting to insure nutsedge kill.

5. Are there any variety or cultivar issues associated with this alternative?

6. Restrictions on Alternative Use

This information will be used to determine the amount of methyl bromide needed.

	% of Area	Details
Regulatory Restriction		
- Label Restriction	yes - 100%	preplant restriction
- Township Caps	none	
Soil Restriction	none	
Pest Resistant To Alternative	yes - 100%	this alternative not highly effective
Organic Matter Restriction	none	
Off Site Damage (outgassing)	yes - 100%	potential
Other Restrictions (Describe)	none	

03-001

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: glyphosate [Insert Alternative]

7. Use Rate of Chemical Alternative

Active Ingredient (a.i.)	Name of Product and Formulation	Quantity a.i. per Acre	Units (gals, lbs. Etc.)	# of Acres Treated	# of Applications per Year
<u>glyphosate</u>	<u>Roundup & others</u>	<u>.8</u>	<u>lb</u>	<u>100%</u>	<u>1-2 per yr</u>

8. Non-Chemical Pest Control (please describe)

(Indicate when fumigation, major crop and pest management practices typically occur by shading the appropriate cells. Show a second crop if part of the fumigation cycle. If the fumigation cycle is longer than one year change the months to an appropriate interval. These tables are for annual crops but more than one crop may benefit from one methyl bromide fumigation. If application covers multiple crops/crop groupings not grown sequentially, they will need to provide this information for all crops/crop groupings. Please adjust timeline as necessary. **Please provide additional comments or description below or on a separate page.** Please begin the timeline with the first land preparation. For perennials, please begin with the year of land preparation and fumigation and indicate the years of production by yield or percentage of full production.)

9. Alternative Timeline

Beginning Fumigation Cycle	Approximate Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation					TC	TC	C	SC	C			
Fumigation					TC	TC			S			
Planting						T		T	S	S		
Harvest					S	SC	SC	TC	C			
Fallow	TC	TC	TC	TC			S	S		TC	TC	TC
Other Key Crop Steps												
Other Key Pest Steps												

T = tomato, pepper
C = cucurbit
S = strawberry

Continuation of Alternative Cycle (if needed)	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation												
Fumigation												
Planting												
Harvest												
Fallow												
Other Key Crop Steps												
Other Key Pest Steps												

Comments:

(nutsedge)
Crop land infested with weeds, need to be sprayed two-three times prior to planting crop.

[Insert Alternative]

[illegible]

Yellow Nutsedge (*Cyperus esculentus*) Control and Tuber Yield with Glyphosate and Glufosinate¹

KELLY A. NELSON, KAREN A. RENNER, and DONALD PENNER²

Abstract: Greenhouse and field research was conducted to determine the effect of glufosinate, glyphosate, and glyphosate plus additional adjuvant on yellow nutsedge control and tuber production. Glyphosate at 0.84 kg/ha reduced yellow nutsedge dry weight 64%, whereas glufosinate at 0.4 kg/ha reduced dry weight only 22% when averaged over diammonium sulfate (DAS) and spray volume. Furthermore, yellow nutsedge dry weight was reduced 53% in the presence and 34% in the absence of DAS; however, dry weights were similar when spray volumes of glufosinate or glyphosate ranged from 140 to 1038 L/ha. Yellow nutsedge control with glyphosate and glufosinate increased to 88 and 68%, respectively, when the herbicides were injected into the plant. In the field, glufosinate at 0.4 kg/ha and glyphosate at 0.84 kg/ha controlled yellow nutsedge 19 and 53%, respectively. Glyphosate reduced yellow nutsedge tuber density 51%, tuber fresh weight 59%, and tuber sprouting 17% 42 wk after treatment in the field. The addition of nonionic surfactant, methylated seed oil, or crop oil concentrate to glyphosate plus DAS did not increase yellow nutsedge control with glyphosate in the greenhouse or field.

Nomenclature: Crop oil concentrate; diammonium sulfate; dose-response; glufosinate; glyphosate; methylated seed oil; nonionic surfactant; yellow nutsedge, *Cyperus esculentus* L. #3 CYPES.

Additional index words: Perennial weed, spray volume, tuber production.

Abbreviations: COC, crop oil concentrate; DAS, diammonium sulfate ((NH₄)₂SO₄); GR₅₀, rate causing 50% growth reduction; MSO, methylated seed oil; NIS, nonionic surfactant; WAT, weeks after treatment.

INTRODUCTION

Yellow nutsedge is a problematic perennial weed found throughout the world in crop production fields (Holm et al. 1991; Schippers et al. 1995). Tubers produced at the terminal end of the rhizome are primarily responsible for the propagation and spread of yellow nutsedge. The introduction of glyphosate- and glufosinate-resistant crop varieties has provided producers with opportunities for nonselective weed control and additional options for perennial weed management. Glyphosate has been evaluated as a nonselective herbicide for the control of numerous perennial weeds, including bermudagrass [*Cynodon dactylon* (L.) Pers.] (Jordan 1977), johnsongrass [*Sorghum halepense* (L.) Pers.] (Salisbury et al. 1991), quackgrass [*Elytrigia repens* (L.) Nevski] (Claus

and Behrens 1976), hemp dogbane (*Apocynum cannabinum* L.) (Schultz and Burnside 1980), Canada thistle [*Cirsium arvense* (L.) Scop.] (Darwent et al. 1994), purple nutsedge (*Cyperus rotundus* L.) (Bariuan et al. 1999; Zandstra et al. 1974), and yellow nutsedge (Appleby and Paller 1978; Pereira and Crabtree 1986; Stoller et al. 1975).

Yellow nutsedge is difficult to control with glyphosate. The glyphosate application rate and the plant age at the time of application influence yellow nutsedge control and viable tuber production (Appleby and Paller 1978; Keeley et al. 1985; Pereira and Crabtree 1986; Stoller et al. 1975). Regrowth of yellow nutsedge after an application of glyphosate at 1.1 to 2.2 kg/ha (Pereira and Crabtree 1986) and, conversely, control with glyphosate at 1.1 kg/ha or more (Derr and Wilcut 1993; Stoller et al. 1975) have been reported.

Application variables, such as reduced spray volume, the addition of diammonium sulfate (DAS), and the use of an additional adjuvant increased weed control with glyphosate (Buhler and Burnside 1983, 1987; Jordan et al. 1997; Krausz et al. 1996). However, these factors have not been investigated to determine their influence

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³ Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk in WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

on yellow nutsedge control with glyphosate. Additional adjuvant is known to increase herbicide absorption and weed control with other herbicides under drought conditions (Wanamarta and Penner 1989). The cuticle is the major limiting barrier for herbicide absorption under such conditions, and yellow nutsedge has a thick waxy cuticle on the adaxial leaf surface (Schipper et al. 1995). Because adjuvants increase efficacy under hot, dry conditions, additional adjuvant with glyphosate may increase yellow nutsedge control. Furthermore, several premixtures of glyphosate with other herbicides are currently being sold. An additional adjuvant for the second herbicide may be recommended to increase control.

Research with glufosinate has focused on annual weed control (Higgins et al. 1991; Krausz et al. 1999; Steckel et al. 1997b; Tharp et al. 1999). Research on perennial weed control with glufosinate is limited (Donn 1982). No research has compared perennial weed control with glyphosate and glufosinate or studied the effect of glufosinate on yellow nutsedge tuber production.

Therefore, the objectives of this research were to determine (1) the effect of spray volume and DAS on yellow nutsedge control with glyphosate and glufosinate, (2) the effect of glyphosate and glufosinate on yellow nutsedge control and tuber yield, and (3) if an additional adjuvant with glyphosate plus DAS affected yellow nutsedge control.

MATERIALS AND METHODS

Greenhouse. Locally collected yellow nutsedge tubers (Kent Co., Michigan) were planted in 910-ml plastic pots in BACCTO potting soil.⁴ A single tuber was planted in each pot, and plants were fertilized with 0.1 g of a water-soluble fertilizer (20% N, 20% P₂O₅, 20% K₂O) in 50 ml of water every 2 wk and surface irrigated as required. Plants were grown in a greenhouse with a 16-h photoperiod of natural and supplemental sodium vapor lighting, which provided a photosynthetic photon flux density⁵ of 120 $\mu\text{E}/\text{m}^2/\text{s}$. Experiments were conducted in the fall and spring. These cultural methods were similar for all research unless otherwise described.

Effect of Spray Volume and DAS. Glyphosate⁶ at 0.84 kg ae/ha and glufosinate at 0.4 kg ae/ha were applied at four spray volumes in the absence and presence of DAS at 20 g/L to yellow nutsedge 15 cm in height with six

leaves. Herbicides were applied at 12:30 P.M. with a traveling-belt sprayer traveling at 1.5 km/h at a spray pressure of 152 kPa. Spray volume was varied using 8001, 8002, 8004, and 8008 flat-fan nozzles⁷ at the same pressure to attain an output of 140, 271, 542, and 1,038 L/ha, respectively. Aboveground yellow nutsedge shoot tissue was harvested 4 wk after treatment (WAT), oven-dried, and the percent dry weight reduction compared with the untreated control calculated. The experiment was analyzed as a three-factor randomized complete block design with four replications and was repeated. The factors were herbicide treatment (glyphosate and glufosinate), presence or absence of DAS, and spray volume. Data were subjected to ANOVA, means were separated using Fisher's Protected LSD ($P \leq 0.05$), and the main effects for each factor are presented because no interactions occurred.

Influence of the Cuticle on Yellow Nutsedge Control.

Yellow nutsedge plants were grown in potting soil, as described previously. Herbicides were injected with a syringe⁸ into plants that were 15 cm tall with six leaves. A volume of 10 μL of solution injected above the basal bulb was equivalent to the postemergence application rate of glufosinate at 0.4 kg/ha and glyphosate at 0.84 kg/ha. Herbicides were injected above the basal bulb to overcome any effects of the thick waxy cuticle on absorption. As controls, plants were injected with water alone. This study was arranged as a randomized complete block design with four replications and was repeated. Yellow nutsedge height and visual control 4 WAT were recorded, subjected to ANOVA, and the means separated using Fisher's Protected LSD ($P \leq 0.05$).

Effect of Glyphosate, Glufosinate, and an Additional Adjuvant with Glyphosate.

Yellow nutsedge tubers were sprouted in a Freas 815 Incubator⁹ between two moist filter papers for 3 d at 31 C before planting. Two moderately sized (5 to 8 mm) sprouted tubers (sprouts 5 to 20 mm long) were transferred to 4-L pots of Spinks loamy sand (sand, mixed, mesic Psammentic Hapludalfs). Herbicide treatments included glufosinate at 0.4 kg/ha plus DAS at 20 g/L and glyphosate at 0.84 kg/ha plus DAS at 20 g/L applied alone and with nonionic

⁴ BACCTO, Michigan Peat Co., Houston, TX 77098.

⁵ LI-COR, 4421 Superior Street, Lincoln, NE 68504.

⁶ Roundup Ultra[®], isopropylamine salt of glyphosate with surfactant, Monsanto, St. Louis, MO 63167.

⁷ Teejet, Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60188.

⁸ Hamilton Company, P.O. Box 10030, Reno, NV 89520-0012.

⁹ Precision Scientific Co., 3737 West Cortland Street, Chicago, IL 60647.

surfactant¹⁰ (NIS) at 0.25% v/v, crop oil concentrate¹¹ (COC) at 1.3% v/v, and methylated seed oil¹² (MSO) at 1.0% v/v. Yellow nutsedge was 15 cm tall with six leaves at the time of application. Herbicides were applied at 6:00 P.M. with a traveling-belt sprayer traveling at 1.5 km/h, delivering 234 L/ha at 193 kPa with an 8001 even flat-fan nozzle. Plants were rated visually on a scale of 0 (no visible injury or plant suppression) to 100% (complete plant death) control 4 and 14 WAT. Plants were harvested after the untreated control had flowered. Plant height, aboveground dry weight, root fresh weight, tuber density, and tuber fresh weight were measured 14 WAT. Percent dry weight reduction was calculated as $100[1 - (\text{treated plant dry weight} / \text{untreated plant dry weight})]$. The experiment was arranged as a randomized complete block design with four replications and was repeated. Data were subjected to ANOVA, and means were separated using Fisher's Protected LSD ($P \leq (0.05)$).

Dose-Response Experiment. A dose-response comparison of glyphosate and glufosinate applied at 0, 0.02, 0.08, 0.35, 1.4, 5.6, and 22.4 kg/ha was arranged in a completely randomized design with five replications and was repeated twice. All treatments included 20 g/L spray-grade DAS. Herbicides were applied at 12:00 P.M. with a traveling-belt sprayer moving at 1.5 km/h, delivering 234 L/ha at 193 kPa, and equipped with an 8001 even flat-fan nozzle. Yellow nutsedge was 15 cm tall with six leaves at the time of application. Aboveground plant shoot tissue was harvested 4 WAT, oven-dried, and the dry weight reduction calculated as a percent of the untreated control. Data were subjected to a nonlinear regression analysis using a log-logistic dose-response model, as previously described by Schabenberger et al. (1999).

Field. Research was conducted in 1997 near Alto, MI, and in 1998 at East Lansing, MI, in fields with a history of heavy yellow nutsedge infestation. The soil was a Boyer sandy loam (coarse-loamy, mixed, mesic Typic Hapludalf) with 2.9% organic matter and pH 6.6 in 1997 and a Marlette sandy loam (fine-loamy, mixed mesic Glossoboric Hapludalf) with 1.7% organic matter and pH 6.7 in 1998. The fields were mechanically tilled 8 cm deep on May 27, 1997 and 6 cm deep on May 13, 1998.

Herbicide treatments included glyphosate at 0.84 kg/ha plus DAS at 20 g/L applied alone and with NIS at 0.25% v/v, COC at 1.3% v/v, and MSO at 1.0% v/v. Glufosinate was also applied at 0.4 kg/ha with DAS at 20 g/L. Yellow nutsedge plants were 10 to 20 cm tall with four to eight leaves at the time of application. Herbicides were applied on June 26, 1997 and June 23, 1998 with a tractor-mounted compressed-air sprayer traveling at 6.3 km/h, delivering 178 L/ha at 207 kPa, and equipped with 8003 flat-fan nozzles. Treatments were applied at 9:00 P.M. with 25 C air temperature and 37% relative humidity in 1997 and at 7:30 P.M. with 33 C air temperature and 30% relative humidity in 1998.

Weed control was evaluated visually 2, 4, and 8 WAT; heights were measured at 2, 4, and 6 WAT, and two 30-by-30-cm quadrats from each plot were harvested 8 WAT and oven-dried to evaluate shoot density and vegetative biomass. Eight soil cores, 10 cm in diameter, were randomly sampled from each plot in April (42 WAT) of the year after herbicide treatment to a 20-cm depth. Tubers were separated from the soil with a custom-modified Kenmore 80¹³ clothes washer machine. Initial tuber densities were measured from each replication in the field before herbicide application by randomly removing 24 soil cores from each replication. Tubers were counted and weighed for each treatment. Initial tuber density averaged over both years was 2,320 tubers/m², with a fresh weight of 328 g/m². Thirty hard tubers were randomly sampled from each plot. The tubers were arranged between two pieces of moist filter paper, placed in 150-by-15-mm petri dishes,¹⁴ and transferred to an incubator set at 30 C to determine the effect of herbicide treatments on tuber sprouting the following year. Tubers were evaluated for sprouting weekly for 3 wk after placement in the incubator. Sprouted tubers were counted and removed upon evaluation. A tuber was considered sprouted when a bud protruded from the scales of the tuber (Holt and Orcutt 1996).

The experiment was arranged as a randomized complete block design with four replicates each year. Individual plots were 3 by 6.1 m. Data were subjected to ANOVA. Field and greenhouse visual control ratings were transformed to the arcsine square root; however, transformation did not affect data interpretation, and untransformed data are presented. Visual control data were subjected to an *F* Max test for homogeneity (Kuehl 1994), and data were combined over locations because

¹⁰ Activator-90®, a mixture of alkyl polyoxyethylene ether and free fatty acids, Loveland Industries Inc., P.O. Box 1289, Greeley, CO 80632.

¹¹ Herbimax®, 83% petroleum oil and 17% surfactant, Loveland Industries Inc., P.O. Box 1289, Greeley, CO 80632.

¹² SunIt-II®, methylated seed oil and emulsifiers, Agsco, Inc., P.O. Box 13458, Grand Forks, ND 58208-3458.

¹³ Sears, Roebuck, and Co., 3333 Beverly Road, Hoffman Estates, IL 60179.

¹⁴ VWR Scientific Products, 800 E. Fabyan Pkwy., Batavia, IL 60510.

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Table 1. Yellow nutsedge dry weight reduction 4 wk after treatment as influenced by glyphosate and glufosinate, diammonium sulfate, and spray volume. Treatment means are averaged across main effects.

Treatment	Dry weight reduction
	%
Herbicide	
Glufosinate 0.4 kg ae/ha	22
Glyphosate 0.84 kg ae/ha	64
LSD ($P=0.05$)	10
Diammonium sulfate	
0 g/L	34
20 g/L	53
LSD ($P=0.05$)	10
Spray volume	
140 L/ha	41
271 L/ha	48
542 L/ha	40
1,038 L/ha	46
LSD ($P=0.05$)	NS

variances for both locations were homogenous. Means were separated using Fisher's Protected LSD ($P \leq 0.05$).

RESULTS AND DISCUSSION

Effect of Spray Volume and DAS. There were no interactions among herbicide, DAS, and spray volume; therefore, the main effects for herbicide, DAS, and spray volume are presented (Table 1). Glyphosate at 0.84 kg/ha reduced yellow nutsedge dry weight 64%, whereas glufosinate at 0.4 kg/ha reduced dry weight only 22% when averaged over DAS and spray volume. In the presence and absence of DAS, yellow nutsedge dry weight was reduced 53 and 34%, respectively. In previous research the addition of DAS increased annual weed control with glufosinate and glyphosate (Blackshaw 1989; Jordan et al. 1997) and purple nutsedge control with glyphosate (Suwunnamek and Parker 1975). In contrast, yellow nutsedge control did not increase when DAS was added to glyphosate in glyphosate-resistant corn (*Zea mays* L.) research (Fischer and Harvey 1998). Increased control of yellow nutsedge with DAS compared with no DAS in this research illustrates the importance of this spray additive in increasing yellow nutsedge suppression with glyphosate and glufosinate.

Yellow nutsedge dry weight was not influenced by the spray volume of the herbicide application (Table 1). Bruce and Kells (1990) have also reported that spray volume did not influence horseweed [*Conyza canadensis* (L.) Cronq.] control with glyphosate. In contrast, low spray volumes increased annual grass control with glyphosate (Buhler and Burnside 1987). The plant morphology of yellow nutsedge may allow the applied her-

Table 2. Height and control of yellow nutsedge 4 wk after treatment as affected by glyphosate and glufosinate injected into plants grown in the greenhouse.

Treatment	Rate	Height	Control
	kg ae/ha	cm	%
Glyphosate	0.84	10	88
Glufosinate	0.4	10	68
Untreated	0	25	0
LSD ($P=0.05$)		3	8

bicide spray solution to accumulate in the whorl of the plants, so there is little effect of spray volume on yellow nutsedge dry weight or herbicide efficacy.

Influence of the Cuticle on Yellow Nutsedge Control.

Glufosinate and glyphosate decreased yellow nutsedge height by 60% 4 WAT (Table 2). Glyphosate at 0.84 kg/ha controlled yellow nutsedge 88%, whereas glufosinate at 0.4 kg/ha provided 68% control. Greater yellow nutsedge control with direct injection compared with foliar broadcast application suggests that absorption across the thick waxy cuticle may be a major limitation to yellow nutsedge control with either herbicide. Common lambsquarters (*Chenopodium album* L.), an annual weed with a waxy cuticle, was the most tolerant weed species to glufosinate and had the least absorption when compared with giant foxtail (*Setaria faberi* Herrm.), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], and velvetleaf (*Abutilon theophrasti* Medik.) (Steckel et al. 1997a).

Effect of Glyphosate, Glufosinate, and an Additional Adjuvant with Glyphosate. Glyphosate at 0.84 kg/ha provided greater yellow nutsedge control than did glufosinate at 0.4 kg/ha in greenhouse and field research (Table 3). Glufosinate and glyphosate reduced tuber fresh weight 22 and 24%, respectively, in the greenhouse. Glyphosate controlled yellow nutsedge 53% 8 WAT, which resulted in a 51% reduction in tuber density, a 59% reduction in tuber fresh weight, and a 17% reduction in tuber sprouting 42 WAT in the field. Tubers that did not sprout remained hard and turgid (data not shown). Other researchers reported a 43 to 45% reduction in shoot fresh weight 10 d after treatment and a 27 to 59% reduction in parent tuber sprouting from a post-emergence application of glyphosate at 0.6 kg/ha to 2- to 4-wk-old plants (Keeley et al. 1985). In contrast, glyphosate at 1.1 and 2.2 kg/ha did not affect yellow nutsedge parent tuber viability in other research (Stoller et al. 1975).

The addition of NIS, COC, or MSO to glyphosate at 0.84 kg/ha plus DAS had no effect on yellow nutsedge control, height, dry weight, tuber density, or fresh weight

Table 3. Yellow nutsedge control, tuber number, fresh weight, and sprouting after glyphosate and glufosinate application in the greenhouse and field in 1997 and 1998.

Herbicide treatment	Rate	Control	Tuber		
			Number	Fresh weight	Sprout ^c
	kg ae/ha	%	no./m ²	g/m ²	%
Greenhouse research ^a					
Glyphosate + DAS	0.84 + 20	29	6,990	700	—
Glufosinate + DAS	0.4 + 20	16	6,320	680	—
Untreated	0	0	7,830	900	—
LSD ($P=0.05$)		8	980	150	—
Field research ^b					
Glyphosate + DAS	0.84 + 20	53	2,540	320	65
Glufosinate + DAS	0.4 + 20	19	3,450	430	83
Untreated	0	0	5,190	770	82
LSD ($P=0.05$)		3	2,180	370	14

^a Greenhouse research evaluated control, tuber number, and tuber fresh weight at 14 wk after treatment and were repeated. Diammonium sulfate (DAS) was applied at 20 g/L.

^b Field research evaluated control 8 wk after treatment, tuber number, and tuber fresh weight 42 wk after treatment.

^c Data were the percentage of 30 hard tubers per plot that sprouted upon visual examination for 3 wk, after placement in an incubator at 30 C. Tubers were randomly selected from soil cores sampled to a 20-cm depth 42 wk after treatment.

in the greenhouse or field (data not shown). Yellow nutsedge leaves appeared bleached and chlorotic at the base of the leaves 1 wk after glyphosate was applied, and new sprouts emerging from the basal bulb allowed propagation of this weed in the greenhouse and field. Similarly, Bariuan et al. (1999) found that organosilicone surfactants did not affect purple nutsedge control with a glyphosate formulation similar to the formulation applied in this research.

Dose-Response Experiment. Yellow nutsedge dry weight decreased as the glyphosate and glufosinate rate increased (Figure 1). Rates causing 50% growth reduction (GR_{50}) of 0.46 and 0.53 kg/ha for glyphosate and glufosinate, respectively, were statistically similar. Appleby and Paller (1978) reported 52, 97, and 100% yellow nutsedge control from glyphosate at 0.6, 1.1, and 1.2 kg/ha, respectively. Research with annual weeds has indicated GR_{50} values from 0.063 to 0.235 kg/ha for glufosinate and from 0.064 to 0.16 kg/ha for glyphosate Steckel et al. 1997b; Tharp et al. 1999). Our GR_{50} values for yellow nutsedge were equal to 55 and 133% of the typical use rates of glyphosate (0.84 kg/ha) and glufosinate (0.4 kg/ha), respectively, applied for annual weed control in glyphosate- or glufosinate-resistant crops. Therefore, yellow nutsedge control in the field could be greater with glyphosate than with glufosinate rates applied for annual weed control.

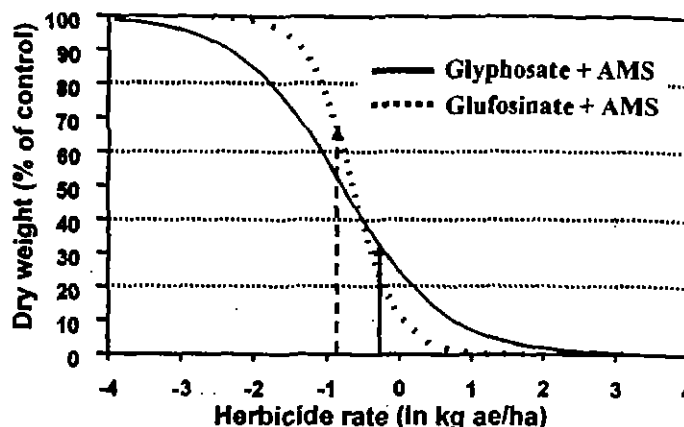


Figure 1. Response of yellow nutsedge shoot dry weight to glyphosate (solid log-logistic curve, dry weight [% of control] = $100/[1 + \exp(1.43 \cdot (\ln(\text{kg ae/ha})/0.456))]$, $R^2 = 0.80$), and glufosinate (dotted log-logistic curve, dry weight [% of control] = $100/[1 + \exp(3.26 \cdot (\ln(\text{kg ae/ha})/0.529))]$, $R^2 = 0.80$) plus diammonium sulfate (DAS) at 20 g/L 4 wk after treatment. GR_{50} values for glyphosate and glufosinate were 0.46 and 0.53 kg/ha, respectively. Vertical lines with arrows indicate the predicted control with glyphosate at 0.84 kg/ha and glufosinate at 0.4 kg/ha.

In conclusion, neither glufosinate at 0.4 kg/ha nor glyphosate at 0.84 kg/ha controlled yellow nutsedge foliage greater than 65%. Glyphosate provided greater above-ground yellow nutsedge control than did glufosinate, but treatments resulted in similar tuber production. The addition of DAS increased yellow nutsedge control with glyphosate and glufosinate, but changes in spray volume with either herbicide or an additional adjuvant did not affect yellow nutsedge control. Split applications of these herbicides or tank mixture combinations with other postemergence herbicides would be required to increase yellow nutsedge control and to reduce tuber production in glyphosate- or glufosinate-resistant crops. Yellow nutsedge control in corn (*Zea Mays* L.) and soybean [*Glycine max* (L.) Merr.] may increase when compared with the control in this research because the crop would compete with yellow nutsedge for light, moisture, and nutrients.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: Metam Sodium [Insert Alternative]

1. Yield Loss & Pest Control When Comparing This Alternative to Methyl Bromide

Provide numerical estimates where possible.

Study # (list below)	Pest Being Tested	% Yield Loss *	% Pest Control *	Details
1	Purple nutsedge		0-6%	Did not control purple nutsedge
2				
3				
4				
5				
Enter Average Loss				

* If no yield or quality loss information is given we will assume no losses. Only provide pest control information if yield or quality loss information is not available.

2. Study Information

For the information in #1 above list: the study name, authors, publication, date, and if a copy is attached.

Study #	Attached?	Details
1	X	Soil solarization options in Aydin strawberry without
2		methyl bromide; Benlioglu, S. O. Boz, A. Yildiz, G. Kaskavalci,
3		K. Benlioglu; 2002; 2002 Annual International Research
4		Conference on Methyl Bromide Alternatives and Admissions
5		Reductions

3. Quality Loss *

Describe quality impacts such as: percent smaller fruit, reduced grade, smaller plants, crop damage, disease vector, etc. Refer to market category question in Worksheet 2-C.

Market Category	Yield with Methyl Bromide	Units	Yield With Alternative	Units	Quality Impact Description
marketable fruit	not in study		30585	kg/ha	The non treated control yielded 43585 kg/ha averaged over 4 locations. This alternative was 116% of non treated control yield

4. Are there any production delays (planting/ harvesting) associated with this alternative?

Yes

☒

No

☐

(If yes, please explain)

Delays in harvest can occur resulting from nutsedge infestations

5. Are there any variety or cultivar issues associated with this alternative?

6. Restrictions on Alternative Use

This information will be used to determine the amount of methyl bromide needed.

	% of Area	Details
Regulatory Restriction	none	
- Label Restriction	none	
- Township Caps	none	
Soil Restriction	none	
Pest Resistant To Alternative	yes	not controlled
Organic Matter Restriction	none	
Off Site Damage (outgassing)	none	
Other Restrictions (Describe)	none	

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: metam [Insert Alternative]

7. Use Rate of Chemical Alternative

Active Ingredient (a.i.)	Name of Product and Formulation	Quantity a.i. per Acre	Units (gals, lbs. Etc.)	# of Acres Treated	# of Applications per Year
<u>metam</u>		<u>100 ml/m²</u>	<u>m</u>	<u>21 in stud</u>	<u>1</u>

8. Non-Chemical Pest Control (please describe)

9. Alternative Timeline

(Indicate when fumigation, major crop and pest management practices typically occur by shading the appropriate cells. Show a second crop if part of the fumigation cycle. If the fumigation cycle is longer than one year change the months to an appropriate interval. These tables are for annual crops but more than one crop may benefit from one methyl bromide fumigation. If application covers multiple crops/crop groupings not grown sequentially, they will need to provide this information for all crops/crop groupings. Please adjust timeline as necessary. **Please provide additional comments or description below or on a separate page.** Please begin the timeline with the first land preparation. For perennials, please begin with the year of land preparation and fumigation and indicate the years of production by yield or percentage of full production.)

Beginning Fumigation Cycle	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation				TC	TC	TC	TC	S	S			
Fumigation				TC	TC	C	TC	SC	S			
Planting				TC	TC	TC	TC	TC	S	S		
Harvest					S	S	S					
Fallow												
Other Key Crop Steps												
Other Key Pest Steps												

T = tomato, pepper
C = cucurbit
S = strawberry

Continuation of Alternative Cycle (if needed)	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation												
Fumigation												
Planting												
Harvest												
Fallow												
Other Key Crop Steps												
Other Key Pest Steps												

Comments:

Alternative:

[Insert Alternative]

[illegible]

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SOIL SOLARIZATION OPTIONS in AYDIN STRAWBERRY WITHOUT METHYL BROMIDE

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Introduction

The general climate of Aydin is Mediterranean with mild winters and dry summer. Most of the strawberry production in Aydin centers on Sultanhisar town. Plants are usually set in the summer as either frigo plants or pot-rooted runners using predominantly California cultivars (Camarosa, Sweet Charlie). Most of the production is on raised beds on black plastic mulch in unheated high tunnels.

Since 2000, a project supported by the World Bank (TTGV-P2/29M) has been conducted to introduce alternative products or farming systems to methyl bromide in protected strawberry of Aydin province of Turkey. 1999-2000 trials as well as general data and several results were reported on the last MBAO conference at San Diego (Benlioglu et al., 2001).

The purpose of this research is to apply the best chemical alternative, dazomet and metam sodium, and the best nonchemical alternative, soil solarization, for soilborne pathogen and weed control and crop response over two years on the same strawberry field.

Methods

Four commercial strawberry fields in Sultanhisar were chosen. All four-study sites have loamy soils. At each of four fields four separate treatments were made: (1) standard soil solarization (44 days between 26th June- 9th August), (2) dazomet (50 g / m² granular formulation incorporated into soil by rototiller after applying with special granular sprayer and treated soil was mulched with polyethylene (PE, 110 μ thick) film, (3) metam sodium (100ml / m² with drip irrigation under the PE, (4) untreated control.

In one location two additional different treatments were also made: (5) raised bed solarization (first strawberry planting beds were prepared and then covered with PE, and solarized for 44 days between 26th June- 9th August), (6) 50 ml / m² metam sodium with drip irrigation under PE after 15 days standard soil solarization. In this field, soil temperatures in three different depths (5, 10, 20 cm) and soil moisture were hourly recorded in untreated control and solarization plots by using WatchDog data loggers (Spectrum Technologies, Inc) for the period of solarization.

The plantation with cv. "Camarosa" was carried out in the first half of August and the beds were covered with standard black plastic mulch in mid September. Conventional practices for annual strawberry production and the pest management for the field were followed. Berries were picked for fresh market at least weekly from the beginning of March until June 12th 2002.

Over the course of each field trial, treatments were evaluated for their effects on the following variables: (1) strawberry marketable yield, (2) control of weeds, (3) control of soilborne fungal diseases.

Results

The season total marketable fruit yields from the four trials are reported in Table 1. All treatments resulted in a yield increase, relative to the untreated control, with exception of the metam sodium and solarization + 1/2 metam sodium treatment in location I. However, raised bed solarization requiring no soil cultivation after solarization gave the highest fruit yields in all treatments of location I. Data from the WatchDog units kept on raised bed solarization and control plots are shown in Figure 1 and 2. The maximum soil temperatures at the 5 and 10 cm depth of raised bed solarization plot were about 55 and 50 C° during solarization period, respectively. We also noticed that there was about 10 C° difference between the temperatures at the depth of 5 and 10 cm of raised bed solarization and control plots. The soil temperature differences at the depth of 20 cm stayed about 5 C° between raised bed solarization and control plots.

Table 1. Total marketable and relative yields of Camorosa from harvest 2002 at four locations (I- N. Ozyigit, II- A. Turkoglu, III- D. Aktas, IV- A. Erdogan) in Sultanhisar.

Treatments	Locations							
	I*		II		III		IV	
	Total Yield kg/ha	Relat. Yield**	Total Yield kg/ha	Relat. Yield	Total Yield kg/ha	Relat. Yield	Total Yield kg/ha	Relat. Yield
Standard Solarization	41490	101	59860	109	43410	105	41890	113
Raised Bed Solarization	53760	131	-	-	-	-	-	-
Dazomet	46040	111	62690	115	47170	114	44120	119
Metam Sodium	40640	99	60070	110	55130	133	46500	125
Solarization + 1/2 M. sodium	39990	98	-	-	-	-	-	-
Untreated control	40990	100	54720	100	41520	100	37110	100

(*) Plot sizes at each location are 75, 65, 55 and 55 m long tunnels containing 4 raised planting beds, respectively

(**) Relative yield = % of productivity versus control

The effect of fumigants and soil solarization on emergence of native weed populations was evaluated periodically observing the soil coverage of weed species in a wooden frame (50 x 50 cm) by randomly using 9 times in each plot. The coverage of each weed species in total weed infestation was given as a percentage and the effect of each treatment was found by comparison with untreated control (Boz et al., 2002). Common weeds in 4 experimental fields were common purslane (*Portulaca oleracea*), purple nutsedge (*Cyperus rotundus*), annual blue grass (*Poa annua*), horseweed (*Conyza canadensis*) and redroot pigweed (*Amaranthus retroflexus*) (Table 2 and 3). All fumigants and soil solarization treatments reduced annual blue grass population. Likewise raised bed solarization and dazomet were found to be highly effective on common purslane. Standard solarization and metam sodium showed contradictory effect to common purslane while 15-day-solarization plus half dosage of metam sodium gave promising effect to the same weed species. However, none of the treatments could control purple nutsedge and horseweed in all locations.

Table 2. The effect of alternative fumigants and soil solarization on common purslane, purple nutsedge and redroot pigweed at three locations in Sultanhisar

Treatments	Locations				
	I	II		III	
	Common purslane	Common purslane	Purple nutsedge	Common purslane	Redroot pigweed
	August 27, 2001*	August 27, 2001		September 12, 2001	
Standard Solarization	**28.10 (00.0)	5.67 (03.7)	38.33 (00.0)	9.34 (72.7)	2.50 (70.0)
Raised Bed Solarization	1.34 (93.7)	-	-	-	-
Dazomet	1.79 (91.6)	0.50 (91.5)	43.89 (00.0)	11.8 (65.5)	1.45 (82.6)
Metam Sodium	3.58 (83.3)	1.22 (79.3)	45.00 (00.0)	11.3 (67.0)	2.61 (68.7)
Solarization + 1/2 M. sodium	0.88 (95.9)	-	-	-	-
Untreated control	21.42	5.89	22.89	34.2	8.33

(*) Weed sampling was performed on the raised planting beds just before covering black mulch.

(**) The percentage of coverage of each weed species, the numbers in brackets show the percentage weed control

Table 3. The effect of alternative fumigants and soil solarization on common purslane, purple nutsedge and annual blue grass and horseweed at four locations in Sultanhisar

Treatments	Locations							
	I		II			III	IV	
	Annual blue grass	Common Purslane	Common Purslane	Horseweed	Purple nutsedge	Horseweed	Annual blue grass	Horseweed
	August 15, 02 *	May 15, 02 June 12, 02	May 1, 02	April 3, 02	April 3, 02 May 1, 02	March 3, 02	Feb. 20, 02 April 3, 02	April 3, 02
Standard Solarization	0.3(99.3)**	31.41 (1.2)	7.22 (15.7)	5.92 (0.0)	15.53 (0.0)	12.80 (0.0)	0.0 (100)	7.33 (14.3)
Raised Bed Solarization	0.00 (100)	4.08 (87.2)	-	-	-	-	-	-
Dazomet	8.58 (81.9)	6.30 (80.2)	2.11 (75.3)	3.00 (34.5)	2.49 (56.6)	16.70 (0.0)	0.38 (97.0)	12.21 (0.0)
Metam Sodium	3.08 (93.5)	45.9 (00.0)	0.44 (94.9)	9.00 (0.0)	5.42 (5.6)	7.43 (0.0)	0.0 (100)	7.38 (13.7)
Solarization + 1/2 M. sodium	0.25 (99.5)	8.96 (71.8)	-	-	-	-	-	-
Untreated control	47.50	31.78	8.56	4.58	5.74	5.33	12.48	8.55

(*) Weed sampling was performed between the raised planting beds just after covering black mulch and all weeds were removed by hoeing after every sampling.

(**) The percentage of coverage of each weed species, the numbers in brackets show the percentage weed control.

Microbial isolates recovered from the diseased strawberry plants and seedlings indicated that the most frequent soilborne fungi were *Rhizoctonia* spp., *Phytophthora cactorum* and *Verticillium dahliae* in our strawberry fields. Farmers usually lose most of the strawberry plants when they get the second crop from the same field for the next year. The effect of fumigants and soil solarization to soilborne diseases of strawberry after one year from the onset of application is presented in Table 4.

Table 4. The percentage of dead strawberry plants in the experimental plots of location I on August 29, 2002

Treatments	Dosage or solarization time	Dates	Dead Plant (%)
Standard Solarization	44 days	June 26 – August 9, 2001	44.44 ab**
Raised Bed Solarization	44 days	June 26 – August 9, 2001	25.04 c
Dazomet	50 g / m ²	August 2 – August 8, 2001	38.41 b
Metam Sodium	100 ml / m ²	July 26 – August 8, 2001	45.71 ab
Solarization + 1/2 M. sodium	15 days + 50 ml / m ²	July 12 – July 26, 2001	51.18 a
Untreated control			42.06 ab

(*) Dead strawberry plants were counted in each raised bed of four bed tunnel plots in Location I and the percentage of dead plant were counted in comparison with untreated control.

(**) Values in the column with different letters show significant differences at P=0.05 according to the Fisher's least significant difference (LSD) test. Data are means of four replicates.

Conclusions

Our studies on methyl bromide alternatives have been underway. Raised bed solarization gave the most satisfactory results and was found to be good alternative to methyl bromide and our treatments in a cost effective manner. Raised bed solarization requires minimum soil cultivation, gives efficient control to weeds except purple nutsedge until black plastic mulch is wrapped on raised planting beds. Recently, raised bed solarization has began to be very popular among the farmers in our region due to the applicability with used polyethylene sheets and resulting better plant growth and yield. Although we did not detect any plant parasitic nematode (*Meloidogyne* spp. or *Aphelenchoides fragariae*) in our demonstration fields, some weed species (purple nutsedge and horseweed) and soilborne diseases of strawberry are still major problem in our strawberry growing areas and need further investigation.

References

- Benlioglu, S., K. Benlioglu, A. Yildiz, O. Boz, G. Kaskavalci. 2001. Studies on methyl bromide alternatives of strawberries in Aydin province. 2001 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 5-9, San Diego (California) 107-1-3.
- Boz, O., M. N. Dogan, F. Albay. 2002. Determination of weed species on strawberry growing areas in Aydin province of Turkey. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft XVIII, 147-153.

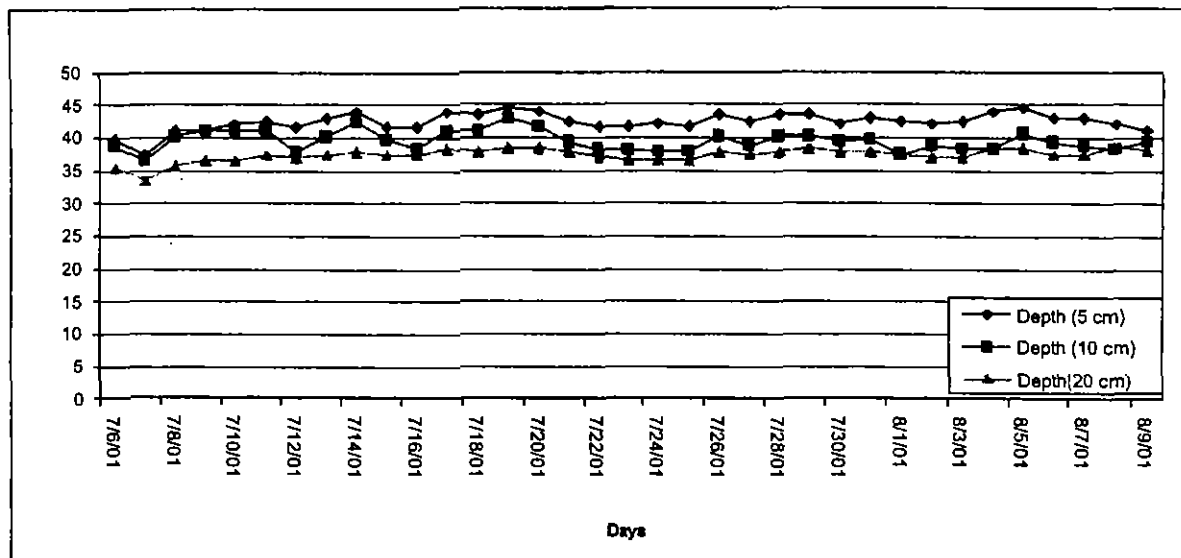


Figure 1. Daily temperature values (16⁰⁰pm) at three different depth of control plot in location 1 between 6th July and 9th August 2001.

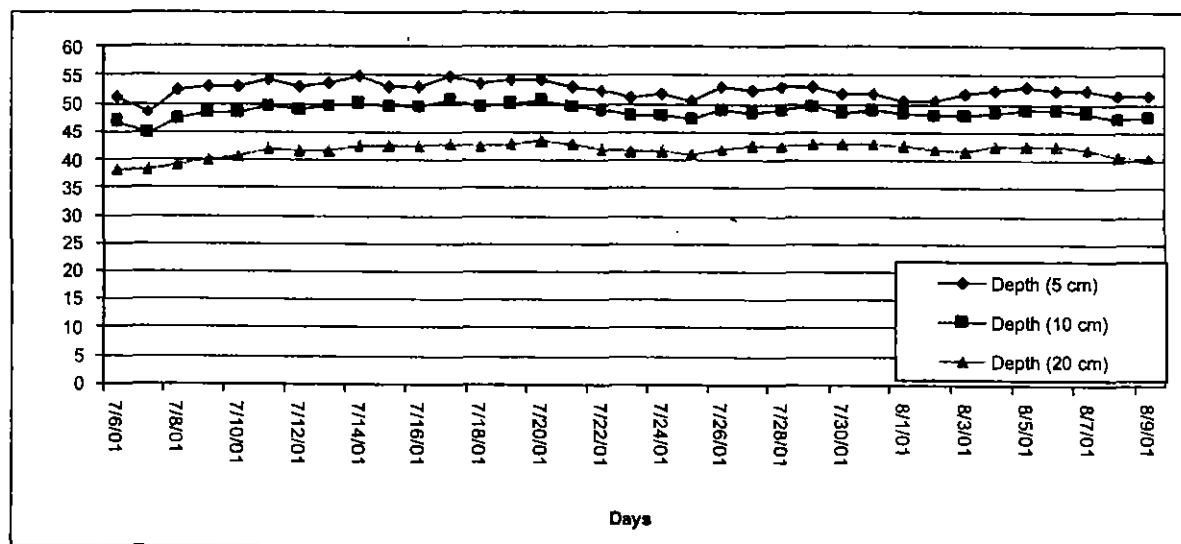


Figure 2. Daily temperature values (16⁰⁰pm) at three different depth of raised bed solarization plot in location 1 between 6th July and 9th August 2001.

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: Soil Solarization [Insert Alternative]

1. Yield Loss & Pest Control When Comparing This Alternative to Methyl Bromide

Provide numerical estimates where possible.

Study # (list below)	Pest Being Tested	% Yield Loss *	% Pest Control *	Details
1	<u>nutsedge, purple</u>		<u>0</u>	<u>strawberry yield was slightly higher than non-treated control</u>
2				
3				
4				
5				
Enter Average Loss				

* If no yield or quality loss information is given we will assume no losses. Only provide pest control information if yield or quality loss information is not available.

2. Study Information

For the information in #1 above list: the study name, authors, publication, date, and if a copy is attached.

Study #	Attached?	Details
1	<u>X</u>	<u>Soil solarization options in Aydin strawberry without methyl bromide; Benlioglu, S. O. Boz, A. Yildiz G. Kaskavalci, K. Benlioglu. 2002. 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.</u>
2		
3		
4		
5		

3. Quality Loss *

Describe quality impacts such as: percent smaller fruit, reduced grade, smaller plants, crop damage, disease vector, etc. Refer to market category question in Worksheet 2-C.

Market Category	Yield with Methyl Bromide	Units	Yield With Alternative	Units	Quality Impact Description
<u>Marketable fruit</u>	<u>not in study</u>		<u>46663</u>	<u>kg/ha</u>	<u>The non-treated control yielded 43585 kg/ha averaged over 4 locations. This alternative was 107% of non-treated control yield.</u>

4. Are there any production delays (planting/ harvesting) associated with this alternative?

Yes

☒

No

☐

(If yes, please explain)

delays can occur from weed competition resulting in delayed harvests.

5. Are there any variety or cultivar issues associated with this alternative?

6. Restrictions on Alternative Use

This information will be used to determine the amount of methyl bromide needed.

	% of Area	Details
Regulatory Restriction	<u>none</u>	
- Label Restriction	<u>none</u>	
- Township Caps	<u>none</u>	
Soil Restriction	<u>none</u>	
Pest Resistant To Alternative	<u>yes</u>	<u>not controlled</u>
Organic Matter Restriction	<u>none</u>	
Off Site Damage (outgassing)	<u>none</u>	
Other Restrictions (Describe)	<u>none</u>	

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: Soil Solarization [Insert Alternative]

7. Use Rate of Chemical Alternative

Active Ingredient (a.i.)	Name of Product and Formulation	Quantity a.i. per Acre	Units (gals, lbs. Etc.)	# of Acres Treated	# of Applications per Year

8. Non-Chemical Pest Control (please describe)

Solarization from June 26 - August 9 : not feasible because not effective.

(Indicate when fumigation, major crop and pest management practices typically occur by shading the appropriate cells. Show a second crop if part of the fumigation cycle. If the fumigation cycle is longer than one year change the months to an appropriate interval. These tables are for annual crops but more than one crop may benefit from one methyl bromide fumigation. If application covers multiple crops/crop groupings not grown sequentially, they will need to provide this information for all crops/crop groupings. Please adjust timeline as necessary. Please provide additional comments or description below or on a separate page. Please begin the timeline with the first land preparation. For perennials, please begin with the year of land preparation and fumigation and indicate the years of production by yield or percentage of full production.)

9. Alternative Timeline

Beginning Fumigation Cycle	Time Interval (e.g. MONTH/YEAR/SEASON)												T = tomato, pepper C = cucumber S = strawberry
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	
Land Preparation				T	T	EST	EST	ST	S	S			
Fumigation				TC	TC		S	S	S	S	S		
Planting				TC	TC			STC	S	S			
Harvest					S	SC	TC	TC	TC				
Fallow	TC	TC	TC				T	T		TC	TC	TC	
Other Key Crop Steps													
Other Key Pest Steps													

Continuation of Alternative Cycle (if needed)	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation												
Fumigation												
Planting												
Harvest												
Fallow												
Other Key Crop Steps												
Other Key Pest Steps												

Comments:

[Insert Alternative]

[illegible]

2002

Annual International Research

Conference on Methyl Bromide

Alternatives and Emissions Reductions

Sponsored by
Methyl Bromide Alternatives Outreach

In cooperation with
Crop Protection Coalition,
U S Environmental Protection Agency
And
U S Department of Agriculture

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SOIL SOLARIZATION OPTIONS in AYDIN STRAWBERRY WITHOUT METHYL BROMIDE

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Introduction

The general climate of Aydin is Mediterranean with mild winters and dry summer. Most of the strawberry production in Aydin centers on Sultanhisar town. Plants are usually set in the summer as either frigo plants or pot-rooted runners using predominantly California cultivars (Camarosa, Sweet Charlie). Most of the production is on raised beds on black plastic mulch in unheated high tunnels.

Since 2000, a project supported by the World Bank (TTGV-P2/29M) has been conducted to introduce alternative products or farming systems to methyl bromide in protected strawberry of Aydin province of Turkey. 1999-2000 trials as well as general data and several results were reported on the last MBAO conference at San Diego (Benlioglu et al., 2001).

The purpose of this research is to apply the best chemical alternative, dazomet and metam sodium, and the best nonchemical alternative, soil solarization, for soilborne pathogen and weed control and crop response over two years on the same strawberry field.

Methods

Four commercial strawberry fields in Sultanhisar were chosen. All four-study sites have loamy soils. At each of four fields four separate treatments were made: (1) standard soil solarization (44 days between 26th June- 9th August), (2) dazomet (50 g / m² granular formulation incorporated into soil by rototiller after applying with special granular sprayer and treated soil was mulched with polyethylene (PE, 110 μ thick) film, (3) metam sodium (100ml / m² with drip irrigation under the PE, (4) untreated control.

In one location two additional different treatments were also made: (5) raised bed solarization (first strawberry planting beds were prepared and then covered with PE, and solarized for 44 days between 26th June- 9th August), (6) 50 ml / m² metam sodium with drip irrigation under PE after 15 days standard soil solarization. In this field, soil temperatures in three different depths (5, 10, 20 cm) and soil moisture were hourly recorded in untreated control and solarization plots by using WatchDog data loggers (Spectrum Technologies, Inc) for the period of solarization.

The plantation with cv. "Camarosa" was carried out in the first half of August and the beds were covered with standard black plastic mulch in mid September. Conventional practices for annual strawberry production and the pest management for the field were followed. Berries were picked for fresh market at least weekly from the beginning of March until June 12th 2002.

Over the course of each field trial, treatments were evaluated for their effects on the following variables: (1) strawberry marketable yield, (2) control of weeds, (3) control of soilborne fungal diseases.

Results

The season total marketable fruit yields from the four trials are reported in Table 1. All treatments resulted in a yield increase, relative to the untreated control, with exception of the metam sodium and solarization + 1/2 metam sodium treatment in location I. However, raised bed solarization requiring no soil cultivation after solarization gave the highest fruit yields in all treatments of location I. Data from the WatchDog units kept on raised bed solarization and control plots are shown in Figure 1 and 2. The maximum soil temperatures at the 5 and 10 cm depth of raised bed solarization plot were about 55 and 50 C° during solarization period, respectively. We also noticed that there was about 10 C° difference between the temperatures at the depth of 5 and 10 cm of raised bed solarization and control plots. The soil temperature differences at the depth of 20 cm stayed about 5 C° between raised bed solarization and control plots.

Table 1. Total marketable and relative yields of Camorosa from harvest 2002 at four locations (I- N. Ozyigit, II- A. Turkoglu, III- D. Aktas, IV- A. Erdogan) in Sultanhisar.

Treatments	Locations							
	I*		II		III		IV	
	Total Yield kg/ha	Relat. Yield**	Total Yield kg/ha	Relat. Yield	Total Yield kg/ha	Relat. Yield	Total Yield kg/ha	Relat. Yield
Standard Solarization	41490	101	59860	109	43410	105	41890	113
Raised Bed Solarization	53760	131	-	-	-	-	-	-
Dazomet	46040	111	62690	115	47170	114	44120	119
Metam Sodium	40640	99	60070	110	55130	133	46500	125
Solarization + 1/2 M. sodium	39990	98	-	-	-	-	-	-
Untreated control	40990	100	54720	100	41520	100	37110	100

(*) Plot sizes at each location are 75, 65, 55 and 55 m long tunnels containing 4 raised planting beds, respectively

(**) Relative yield = % of productivity versus control

The effect of fumigants and soil solarization on emergence of native weed populations was evaluated periodically observing the soil coverage of weed species in a wooden frame (50 x 50 cm) by randomly using 9 times in each plot. The coverage of each weed species in total weed infestation was given as a percentage and the effect of each treatment was found by comparison with untreated control (Boz et al., 2002). Common weeds in 4 experimental fields were common purslane (*Portulaca oleracea*), purple nutsedge (*Cyperus rotundus*), annual blue grass (*Poa annua*), horseweed (*Conyza canadensis*) and redroot pigweed (*Amaranthus retroflexus*) (Table 2 and 3). All fumigants and soil solarization treatments reduced annual blue grass population. Likewise raised bed solarization and dazomet were found to be highly effective on common purslane. Standard solarization and metam sodium showed contradictory effect to common purslane while 15-day-solarization plus half dosage of metam sodium gave promising effect to the same weed species. However, none of the treatments could control purple nutsedge and horseweed in all locations.

Table 2. The effect of alternative fumigants and soil solarization on common purslane, purple nutsedge and redroot pigweed at three locations in Sultanhisar

Treatments	Locations				
	I	II		III	
	Common purslane	Common purslane	Purple nutsedge	Common purslane	Redroot pigweed
	August 27, 2001*	August 27, 2001		September 12, 2001	
Standard Solarization	**28.10 (00.0)	5.67 (03.7)	38.33 (00.0)	9.34 (72.7)	2.50 (70.0)
Raised Bed Solarization	1.34 (93.7)	-	-	-	-
Dazomet	1.79 (91.6)	0.50 (91.5)	43.89 (00.0)	11.8 (65.5)	1.45 (82.6)
Metam Sodium	3.58 (83.3)	1.22 (79.3)	45.00 (00.0)	11.3 (67.0)	2.61 (68.7)
Solarization + 1/2 M. sodium	0.88 (95.9)	-	-	-	-
Untreated control	21.42	5.89	22.89	34.2	8.33

(*) Weed sampling was performed on the raised planting beds just before covering black mulch.

(**) The percentage of coverage of each weed species, the numbers in brackets show the percentage weed control

Table 3. The effect of alternative fumigants and soil solarization on common purslane, purple nutsedge and annual blue grass and horseweed at four locations in Sultanhisar

Treatments	Locations							
	I		II			III	IV	
	Annual blue grass	Common Purslane	Common Purslane	Horseweed	Purple nutsedge	Horseweed	Annual blue grass	Horseweed
	August 15, 02 *	May 15, 02 June 12, 02	May 1, 02	April 3, 02	April 3, 02 May 1, 02	March 3, 02	Feb. 20, 02 April 3, 02	April 3, 02
Standard Solarization	0.3(99.3)**	31.41 (1.2)	7.22 (15.7)	5.92 (0.0)	15.53 (0.0)	12.80 (0.0)	0.0 (100)	7.33 (14.3)
Raised Bed Solarization	0.00 (100)	4.08 (87.2)	-	-	-	-	-	-
Dazomet	8.58 (81.9)	6.30 (80.2)	2.11 (75.3)	3.00 (34.5)	2.49 (56.6)	16.70 (0.0)	0.38 (97.0)	12.21 (0.0)
Metam Sodium	3.08 (93.5)	45.9 (00.0)	0.44 (94.9)	9.00 (0.0)	5.42 (5.6)	7.43 (0.0)	0.0 (100)	7.38 (13.7)
Solarization + 1/2 M. sodium	0.25 (99.5)	8.96 (71.8)	-	-	-	-	-	-
Untreated control	47.50	31.78	8.56	4.58	5.74	5.33	12.48	8.55

(*) Weed sampling was performed between the raised planting beds just after covering black mulch and all weeds were removed by hoeing after every sampling.

(**) The percentage of coverage of each weed species, the numbers in brackets show the percentage weed control.

Microbial isolates recovered from the diseased strawberry plants and seedlings indicated that the most frequent soilborne fungi were *Rhizoctonia* spp., *Phytophthora cactorum* and *Verticillium dahliae* in our strawberry fields. Farmers usually lose most of the strawberry plants when they get the second crop from the same field for the next year. The effect of fumigants and soil solarization to soilborne diseases of strawberry after one year from the onset of application is presented in Table 4.

Table 4. The percentage of dead strawberry plants in the experimental plots of location I on August 29, 2002

Treatments	Dosage or solarization time	Dates	Dead Plant (%)
Standard Solarization	44 days	June 26 – August 9, 2001	44.44 ab**
Raised Bed Solarization	44 days	June 26 – August 9, 2001	25.04 c
Dazomet	50 g / m ²	August 2 – August 8, 2001	38.41 b
Metam Sodium	100 ml / m ²	July 26 – August 8, 2001	45.71 ab
Solarization + 1/2 M. sodium	15 days + 50 ml / m ²	July 12 – July 26, 2001	51.18 a
Untreated control			42.06 ab

(*) Dead strawberry plants were counted in each raised bed of four bed tunnel plots in Location I and the percentage of dead plant were counted in comparison with untreated control.

(**) Values in the column with different letters show significant differences at P=0.05 according to the Fisher's least significant difference (LSD) test. Data are means of four replicates.

Conclusions

Our studies on methyl bromide alternatives have been underway. Raised bed solarization gave the most satisfactory results and was found to be good alternative to methyl bromide and our treatments in a cost effective manner. Raised bed solarization requires minimum soil cultivation, gives efficient control to weeds except purple nutsedge until black plastic mulch is wrapped on raised planting beds. Recently, raised bed solarization has began to be very popular among the farmers in our region due to the applicability with used polyethylene sheets and resulting better plant growth and yield. Although we did not detect any plant parasitic nematode (*Meloidogyne* spp. or *Aphelenchoides fragariae*) in our demonstration fields, some weed species (purple nutsedge and horseweed) and soilborne diseases of strawberry are still major problem in our strawberry growing areas and need further investigation.

References

- Benlioglu, S., K. Benlioglu, A. Yildiz, O. Boz, G. Kaskavalci. 2001. Studies on methyl bromide alternatives of strawberries in Aydin province. 2001 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 5-9, San Diego (California) 107-1-3.
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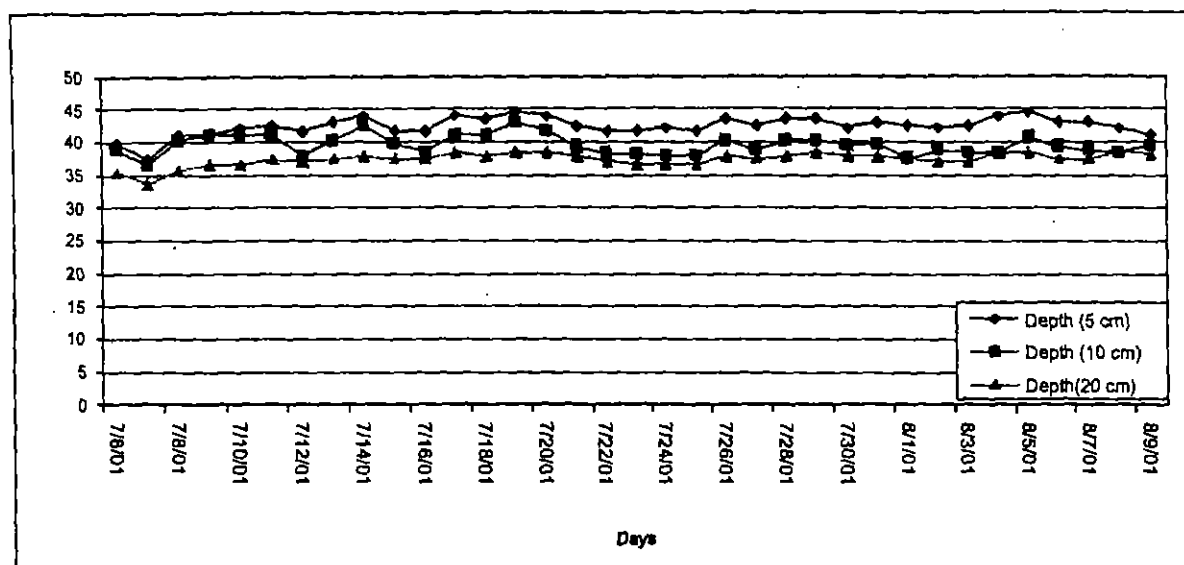


Figure 1. Daily temperature values (16⁰⁰ pm) at three different depth of control plot in location 1 between 6th July and 9th August 2001.

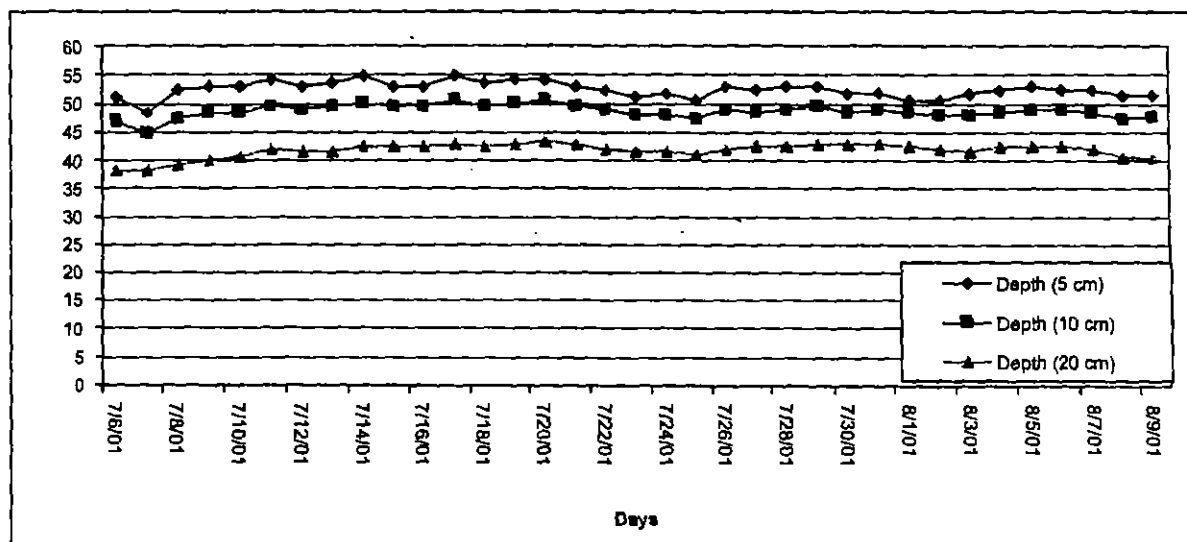


Figure 2. Daily temperature values (16⁰⁰ pm) at three different depth of raised bed solarization plot in location 1 between 6th July and 9th August 2001.

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: Chloropicrin [Insert Alternative]

1. Yield Loss & Pest Control When Comparing This Alternative to Methyl Bromide

Provide numerical estimates where possible.

Study # (list below)	Pest Being Tested	% Yield Loss *	% Pest Control *	Details
1	Yellow nutsedge		0	This study did not include a crop. Chloropicrin stimulated yellow and purple nutsedge tuber emergence.
2	Purple nutsedge		0	
3				
4				
5				
Enter Average Loss				

* If no yield or quality loss information is given we will assume no losses. Only provide pest control information if yield or quality loss information is not available

2. Study Information

For the information in #1 above list: the study name, authors, publication, date, and if a copy is attached.

Study #	Attached?	Details
1	X	Stimulation of nutsedge emergence with chloropicrin. Metis, T.N. and J.P. Gilreath; 2002; 2002 Annual International Research Conference on Methyl Bromide Alternatives and emissions reductions
2		
3		
4		
5		

3. Quality Loss *

Describe quality impacts such as: percent smaller fruit, reduced grade, smaller plants, crop damage, disease vector, etc. Refer to market category question in Worksheet 2-C.

Market Category	Yield with Methyl Bromide	Units	Yield With Alternative	Units	Quality Impact Description
no crop in study					

4. Are there any production delays (planting/ harvesting) associated with this alternative?

Yes

☒

No

☐

(If yes, please explain)

preplant restriction

5. Are there any variety or cultivar issues associated with this alternative?

6. Restrictions on Alternative Use

This information will be used to determine the amount of methyl bromide needed.

	% of Area	Details
Regulatory Restriction		
- Label Restriction		
- Township Caps		
Soil Restriction		
Pest Resistant To Alternative	100%	Nutsedge emergence is stimulated
Organic Matter Restriction		
Off Site Damage (outgassing)		
Other Restrictions (Describe)		

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Alternative: *Chloropicrin* [Insert Alternative]

7. Use Rate of Chemical Alternative

Active Ingredient (a.i.)	Name of Product and Formulation	Quantity a.i. per Acre	Units (gals, lbs. Etc.)	# of Acres Treated	# of Applications per Year
<i>Chloropicrin</i>		<i>50 to 250</i>	<i>lbs</i>	<i>< 1 in study</i>	<i>1-2</i>

8. Non-Chemical Pest Control (please describe)

(Indicate when fumigation, major crop and pest management practices typically occur by shading the appropriate cells. Show a second crop if part of the fumigation cycle. If the fumigation cycle is longer than one year change the months to an appropriate interval. These tables are for annual crops but more than one crop may benefit from one methyl bromide fumigation. If application covers multiple crops/crop groupings not grown sequentially, they will need to provide this information for all crops/crop groupings. Please adjust timeline as necessary. **Please provide additional comments or description below or on a separate page.** Please begin the timeline with the first land preparation. For perennials, please begin with the year of land preparation and fumigation and indicate the years of production by yield or percentage of full production.)

9. Alternative Timeline

Beginning Fumigation Cycle	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation				<i>TC</i>	<i>TC</i>	<i>TC</i>	<i>TC</i>	<i>S</i>	<i>S</i>			
Fumigation				<i>TC</i>	<i>TC</i>	<i>TC</i>	<i>TC</i>					
Planting					<i>TC</i>	<i>TC</i>	<i>TC</i>	<i>TC</i>	<i>SC</i>	<i>S</i>		
Harvest					<i>CS</i>	<i>CS</i>	<i>TCS</i>	<i>TC</i>	<i>TC</i>	<i>C</i>		
Fallow	<i>TC</i>	<i>TC</i>	<i>TC</i>				<i>S</i>	<i>S</i>			<i>TC</i>	<i>TC</i>
Other Key Crop Steps												
Other Key Pest Steps												

Continuation of Alternative Cycle (if needed)	Time Interval (e.g. MONTH/YEAR/SEASON)											
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Land Preparation												
Fumigation												
Planting												
Harvest												
Fallow												
Other Key Crop Steps												
Other Key Pest Steps												

Comments:

Worksheet 3-B(1). Alternatives - Changes in Operating Costs

Alternative:

[Insert Alternative]

[illegible]

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STIMULATION OF NUTSEDGE EMERGENCE WITH CHLOROPICRIN

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Chloropicrin (Pic) is typically combined with soil fumigants, such as methyl bromide and 1,3-dichloropropene, to enhance control of soil-borne diseases. Results of previous field research have suggested that perhaps Pic may have a stimulatory effect on nutsedge emergence. This research was conducted to determine if, and at what rate, Pic stimulates nutsedge emergence.

An experiment was conducted at the Gulf Coast Research and Education Center in Bradenton, Fla. during spring 1999, fall 1999, fall 2000, and fall 2001. Treatments were 6 rates of Pic (0, 50, 100, 150, 200, and 250 lbs/acre Pic) replicated 4 (spring 1999) or 6 (fall of 1999, 2000, and 2001) times in a randomized complete block design. Plots were 30 (fall 1999 and 2000) or 40 (spring 1999 and fall 2001) feet long with 32-inch wide bed-tops. Treatments were established on 2 March in Spring 1999, 9 Sept. in fall 1999, 12 Sept. in fall 2000, and 7 Sept. in fall 2001. Pic was applied through three chisels spaced 12 inches apart to a depth of about 8 inches in raised beds. The beds were covered with polyethylene mulch immediately after Pic application.

Nutsedge (a mixture of *Cyperus esculentus* and *C. rotundus*) populations were higher in spring 1999 than in the fall seasons, and populations in fall 1999 and fall 2000 were greater than those in fall 2001. Therefore, the data for spring 1999 were analyzed separately. Data for fall 1999 and fall 2000 were pooled. Data obtained during fall 2001 were not reported because of low nutsedge counts.

In spring 1999, a rate response of nutsedge population to Pic rate was seen as early as 2 weeks after treatment application (WAT). The number of nutsedge shoots increased from 0.08 to 0.40 shoots/ft² with an increase in Pic rate from 0 to 100 lbs/acre; 0.02 to 0.04 shoots/ft² were present with 150 to 250 lb/acre Pic. At 7, 9, and 16 WAT, the number of shoots increased in a quadratic manner with increases in Pic rate. At 16 WAT, nutsedge shoot counts increased from 18 to 29 shoots/ft² as the Pic rate increased from 0 to 150 lbs/acre, respectively; with further increases in Pic rate from 200 to 250 lbs/acre, the nutsedge population declined from 26 to 14 shoots/ft², respectively.

In fall 1999 and fall 2000, a stimulatory effect of Pic on nutsedge emergence was not observed until later in the season (last counts of the season obtained 8 and 18 WAT in fall 1999 and fall 2000, respectively). The number of nutsedge shoots, averaged over both seasons, increased quadratically from 4 to 7 shoots/ft² with an increase in Pic rate from 0 to 150 pounds, respectively. The nutsedge population declined from 7 to 5 shoots/ft² as the Pic rate was increased from 200 to 250 lbs/acre, respectively.

In conclusion, the results indicated the following:

X Pic stimulated nutsedge emergence in three seasons (spring 1999, fall 1999, and fall 2000), and the stimulatory effect in these seasons was greatest at 100 to 150 lbs/acre.

X An early-season stimulatory effect of Pic on nutsedge emergence was only observed in one (spring 1999) of the three (spring 1999, fall 1999, and fall 2000) seasons during which there were moderate to high nutsedge populations. Thus, additional research is needed to confirm results obtained in spring 1999.

Stimulating nutsedge emergence with Pic at the beginning of a growing season would be beneficial because:

X Chemicals are most effective against nutsedge that is actively growing.

X Herbicides or a drip-applied fumigant such as Vapam could be used to eliminate sprouted tubers before planting a crop.

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Appendix

2002

Modeling the Effects of Weed Interference Periods and Insects on Bell Peppers (*Capsicum annuum*)¹J. RAY FRANK, PAUL H. SCHWARTZ, JR., and WILLIAM E. POTTS²

Abstract. Field experiments were conducted at Frederick, MD, in 1985 and 1986 to determine effects of weed-interference periods and insects on bell peppers. Weed-interference periods of approximately 40 and 60 d reduced both bell pepper fruit number and weight 10 and 50%, respectively. Bell pepper foliage weight was reduced 10 and 50% with approximately 20- and 50-day weed-interference periods. In 1985 and 1986, insect populations were low with an average of 10 and 3% of the pepper fruit infested, respectively. Most infested fruit was damaged by European corn borer. No significant differences in insect infestation of fruit as related to time of weed-interference periods were noted. Nomenclature: Bell pepper, *Capsicum annuum* L. cv. 'Yolo Wonder'; European corn borer, *Ostrinia nubilalis* (Hubner).

Additional index words. Insect population density, weed density, interference, competition, yield reduction, corn borer.

INTRODUCTION

Weed competition studies in some horticultural crops such as tomatoes (*Lycopersicon esculentum* Mill) are well documented (6, 9, 10, 12, 15), but literature regarding the effect of weed infestation as it relates to insect damage and the resultant pepper yield is limited (5).

Bell peppers are a high-value, long-season commodity grown in most of the major vegetable-growing areas of the United States (3). When not controlled, weeds compete vigorously with bell peppers and can reduce yields 70 to 99% (1, 4, 5, 7). In the United States, weeds alone are reported to reduce average pepper yields by 8% (3). Insects are also major problems in bell pepper production (2, 5, 8).

Eshel et al. (4) reported pepper yields were reduced 70% when weeds invaded during the first month after seeding. Frank et al. (5) found that when weeds covered less than 10% of the plot and natural insect populations were left untreated, bell pepper yield was reduced 22 to 32%.

The objectives of this study were to determine effects of different weed-interference periods alone and in conjunction with naturally occurring insect populations on the growth and yield of bell peppers.

MATERIALS AND METHODS

The field experiment was conducted using field-grown transplants of Yolo Wonder bell peppers in 1985 and 1986 at Frederick, MD. The soil was a Duffield silt loam (Ultic Hapludalfs; fine-loamy, mixed, mesic) with 2% organic matter. The pH was maintained near 6.3 with applications of ground limestone.

Experimental design. The experimental design for both years was a randomized complete block, split plot with four replications. The whole-plot factor consisted of insecticide at two levels: insecticide application as needed and no insecticide application. The subplot factor was weed-interference period with nine levels—14, 21, 27, 35, 42, 49, 56, and 63 d, and weed interference throughout the season. The 14-d weed-interference period was applied to two subplots within each whole plot, hence each whole plot consisted of 10 subplots. The dimension of each whole plot was 27.5 by 4.9 m. The dimension of each subplot was 2.7 by 4.9 m. The peppers were transplanted May 30, 1985 and May 22, 1986 on a 0.5- by 1.6-m spacing in four rows per plot with seven plants per row. Data were recorded on the center five plants of the center two rows of each subplot. Consequently, data was collected from an area 7.4 m².

Weed interference. The weed-interference periods were achieved by removing weeds by hand and by rotary tillage from four new subplots per week (eight plots at the first weeding). The newly weeded plots were then kept weed free, using the same techniques weekly, for the remainder of the growing season. All plots were weed free at the time of planting. Weed removal on new plots began 14 d after planting and continued until 63 d after planting. Weeds were not removed from eight subplots for the entire season.

Insect populations and control. Insect populations were controlled or allowed to develop naturally. The whole plots receiving insect control were treated with diazinon [0,0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl)phosphorothioate] at 4.5 kg ai ha⁻¹ preplant incorporated to control soil insects. If foliar-feeding or fruit-infesting insects were observed in these plots, then carbaryl (1-naphthyl N-methylcarbamate) at 2.2 kg ai ha⁻¹ (June 17, 1985, June 13 and July 18, 1986) or acephate (O, S-dimethyl acetylphosphorothioate) at 1.1 kg ai ha⁻¹ (July 11 and August 23, 1985 and June 17, 1986) was applied as needed. The major insect species in the study area were the green peach aphid (*Myzus persicae* Sulzer), European corn borer, red-legged grasshopper (*Melanoplus femurrubrum* De Geer), and other *Melanoplus* species.

Disease control. July 29, 1985 and July 1, 1986 all peppers were treated with kocide (tribasic copper) at 2.2 kg ai ha⁻¹ for bacterial spot. Once each year (1 to 7 d before the first harvest) all peppers were treated with maneb (manganese

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³Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

ethylene-bis dithiocarbamate) at 1.8 kg ai ha⁻¹ for disease control.

Evaluations. Each week, three observers separately estimated the percent of each subplot covered with weeds and then estimated the percent covered by major weed species. The number of broadleaf and grass weeds were also counted in three 0.1-m² quadrats in each subplot.

Mature fruit were harvested from the five middle plants in both rows in each subplot on a regular basis from July 20 to September 26, 1985 and from July 30 to September 26, 1986. All harvested fruit were split open to determine the number infested with insects. At final harvest each year, the 10 pepper plants were cut off at ground level, all remaining fruit was removed, and foliage and fruit were weighed separately. Statistical analysis. In order to determine effects of weed-interference period and insects, regression functions were fitted to four response variables. The four response variables were total fruit number for all harvests (FTNO)⁴, total fruit weight for all harvests (FTWT)⁴, foliage fresh weight at the final harvest (FOWT)⁴, and the percent of the total fruit infested with insects (FTI)⁴. The regressor was weed-interference period (WIP)⁴. For FTNO, FTWT, and FTI the value of the regressor, WIP, for the plots not receiving weed removal was set at 91 and 88 for 1985 and 1986, respectively; these values are the average number of days from planting to harvest each year. For FOWT the value of the regressor, WIP, for the plots with no weed removal was set at 119 and 127 for 1985 and 1986, respectively; these values are the number of days from planting to final harvest each year.

Prior to regression analysis, the four response variables were adjusted for spatial variation in the field by trend analysis (13). The observed responses showed significant spatial trends within each block resulting from the large block size (27.5 m long). The responses were adjusted by removing these trends. The adjustment reduced the variability of the responses and improved the fits of the regression models.

The 10 values of the three adjusted responses, FTNO, FTWT, and FOWT, for each of the 16 yr by insecticide by block combinations were fitted to a nonlinear regression function. The regression function was parameterized as $\text{Max} B^C / (B^C + (\alpha / (1 - \alpha)) \text{WIP}^C)$, where weed-interference period (WIP) is the regressor and $0 < \alpha < 1$ is a given constant. The unknown parameters, Max (> 0), B, and C (> 1), were estimated by nonlinear least squares (11). As weed-interference period increases, the graph of the regression function decreases first at an increasing rate and then at a decreasing rate toward zero. The parameter Max is the value of the function when WIP equals zero and is the maximum value of the function. The parameter B represents the weed-interference period needed for the function to decrease to 100 $\alpha\%$ of its maximum value. The weed-interference periods

needed for the function to decrease to 10 and 50% of its maximum value, denoted W10 and W50, were estimated by setting α equal to 0.1 and 0.5, respectively.

For each of the three responses, FTNO, FTWT, and FOWT, the effects of year and insecticide on the estimates of the parameters, Max, W10, and W50, were evaluated using analysis of variance. The design structure was a split plot with year as the whole-plot factor and insecticide as the subplot factor. The analysis of variance models were fitted by weighted least squares using the reciprocal of the estimated variances of the parameter estimates as weights.

The 10 values of the adjusted responses, FTI, for each of the 16 yr by insecticide by block combinations were fitted to a cubic polynomial regression function. The polynomial coefficients were estimated by least squares.

In order to relate weed-interference period to weed cover, the percent weed cover responses for both years were fitted to an asymptotic growth function by nonlinear least squares. The asymptotic growth regression function was parameterized as $100(1 - \exp(-At))$ where the regressor, t , represents the day after planting on which the percent weed cover was recorded and A is an unknown parameter. The average percent weed cover corresponding to a particular value of weed-interference period (WIP) was calculated as the definite integral of the regression function between zero and WIP divided by WIP; that is, $100(\text{WIP} + (\exp(-A \cdot \text{WIP}) - 1)/A) / \text{WIP}$.

RESULTS AND DISCUSSION

Total fruit number. Fitted regression functions for the total fruit number response for each year and level of insecticide, based on the mean parameter estimates, are given in Figure 1. The mean pepper yield for zero weed interference (the

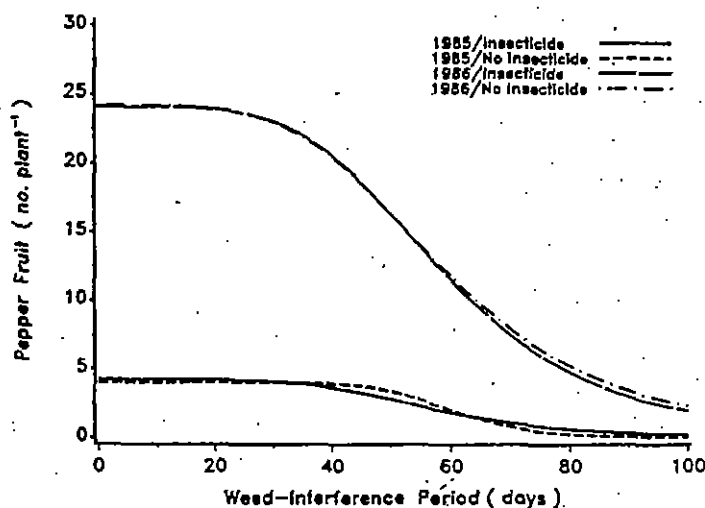


Figure 1. Graph of the predicted regression function for pepper fruit number versus weed-interference period based on the mean estimates of the parameters, Max, B($\alpha = .5$), and C, for 1985 with insecticide (4.2, 57, 5.2), 1985 without insecticide (4.0, 60, 9.2), 1986 with insecticide (24, 59, 4.6), and 1986 without insecticide (24, 59, 4.3).

⁴Abbreviations: FTNO, total fruit number for all harvests; FTWT, total fruit weight for all harvests; FOWT, foliage fresh weight at the final harvest; FTI, percent of total fruit infested with insects; WIP, weed interference period.

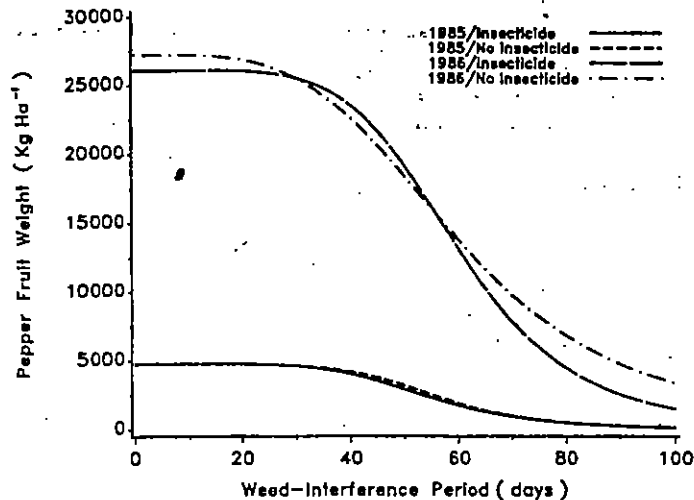


Figure 2. Graph of the predicted regression function for pepper fruit weight versus weed-interference period based on the mean estimates of the parameters, Max , $B(\alpha = .5)$, and C , for 1985 with insecticide (4803, 54, 5.5), 1985 without insecticide (4745, 56, 6.1), 1986 with insecticide (26 084, 60, 5.5), and 1986 without insecticide (27 225, 60, 3.8).

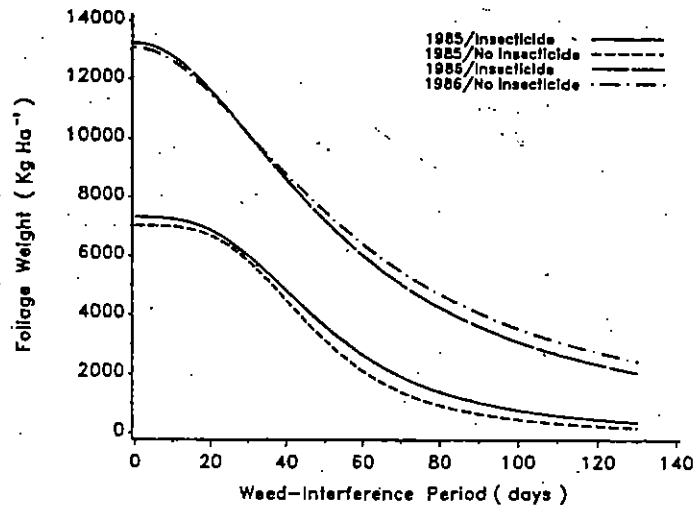


Figure 3. Graph of the predicted regression function for pepper foliage weight versus weed-interference period based on the mean estimates of the parameters, Max , $B(\alpha = .5)$, and C , for 1985 with insecticide (7313, 50, 3.0), 1985 without insecticide (7026, 47, 3.5), 1986 with insecticide (13 221, 55, 2.0), and 1986 without insecticide (13 065, 59, 1.9).

parameter Max) was 4.12 fruit plant⁻¹ in 1985 and 24.1 fruit plant⁻¹ in 1986 (Figure 1). The effect of year on the parameter Max was highly significant (P -value < .0001). The highly significant year effect was probably due to the extremely high night temperatures and lower rainfall during fruit set in 1985 (data not shown). The effect of insecticide on the parameter Max was nonsignificant. The mean weed-interference period needed for a 10% reduction of fruit number (the parameter $W10$) was 43.2 d in 1985 and 37.4 d in 1986. The effect of year on the parameter $W10$ was significant (P -value = .0126). The effect of insecticide on the parameter $W10$ was nonsignificant. There was a lower than expected insect infestation in both years. The mean weed-interference period needed for a 50% reduction of fruit number (the parameter $W50$) was 59.0 d. The effects of year and insecticide on the parameter $W50$ were nonsignificant. Total fruit weight. The fitted regression functions for the total fruit weight response for each year and level of insecticide, based on the mean parameter estimates, are given in Figure 2. The mean pepper weight for zero weed interference was 4775 kg ha⁻¹ in 1985 and 26 654 kg ha⁻¹ in 1986 (Figure 2). The effect of year on the parameter Max was highly significant (P -value < .0001). The effect of insecticide on the parameter Max was nonsignificant. The mean weed-interference period needed for a 10% reduction of fruit weight was 38.5 d. The effects of year and insecticide on the parameter $W10$ were nonsignificant. The mean weed-interference period needed for a 50% reduction of fruit weight was 57.6 d. The effects of year and insecticide on the parameter $W50$ were nonsignificant.

Foliage weight. The fitted regression functions for the foliage fresh weight response for each year and level of insecticide, based on mean parameter estimates, are given in Figure 3.

Mean foliage weight for zero weed interference was 7170 kg ha⁻¹ in 1985 and 13 143 kg ha⁻¹ in 1986. The effect of year on the parameter Max was highly significant (P -value < .0001). The effect of insecticide on the parameter Max was nonsignificant. The mean weed-interference period needed for a 10% reduction of foliage weight was 21.4 d. The effects of year and insecticide on the parameter $W10$ were nonsignificant. The mean WIP needed for a 50% reduction of foliage weight was 48.4 d in 1985 and 56.8 d in 1986 (Figure 3). The effect of year on the parameter $W50$ was significant (P -value = .0171). The effect of insecticide on the parameter $W10$ was nonsignificant.

Insect populations. In both 1985 and 1986, populations of green peach aphids were low (one to five per pepper plant per season) in all plots (data not shown). No significant differences in number of aphids were observed in either year. No significant differences in foliar damage by insects were observed among the insecticide treatments in either year (data not shown). The fitted regression functions for the FTI response for each year and level of insecticide, based on the mean parameter estimates, are given in Figure 4. The insecticide treatment did not significantly affect the FTI responses. Infested bell pepper fruit averaged 10% in 1985 and only 3% in 1986. Most infested fruit was damaged by the European corn borer. The decreasing pattern of the fitted curves in 1985 might suggest that the low weed numbers allowed easier access for the insects.

Weed populations. The average area covered with weeds during the growing season was almost identical for both 1985 and 1986 (Figure 5). In 1985 the total number of broadleaf weeds 0.1 m⁻² decreased as the weed-interference period increased (Table 1). During both 1985 and 1986 the number of grasses 0.1 m⁻² decreased. In 1986 the total number of

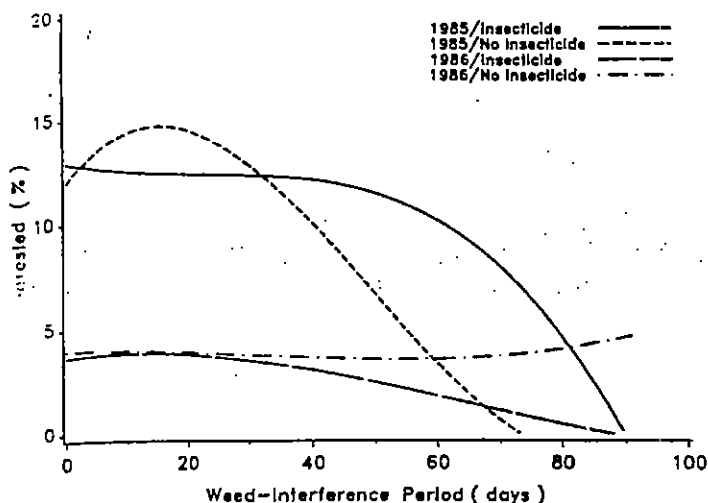


Figure 4. Graph of the predicted regression function for the percent of fruit infested with insects versus weed-interference period based on the mean cubic polynomial coefficients.

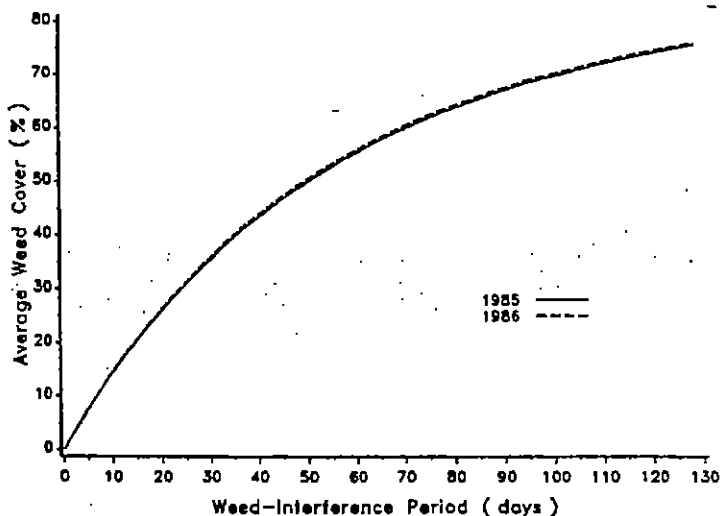


Figure 5. Graph of the average value of the percent weed cover regression function versus weed-interference period where the parameter A was estimated as .0317 in 1985 and .0322 in 1986.

broadleaf weeds 0.1 m^{-2} increased as the weed-interference period increased.

During 1985 and 1986 the major weed species were common lambsquarters (*Chenopodium album* L. #CHEAL³), redroot pigweed (*Amaranthus retroflexus* L. #AMARE), and giant foxtail (*Setaria faberi* Herrm. #SETFA). During 1986 carpetweed (*Mollugo verticillata* L. #MOLUE), common purslane (*Portulaca oleracea* L. #POROL), yellow nutsedge (*Cyperus esculentus* L. #CYPES), and yellow woodsorrel (*Oxalis stricta* L. #OXAST) were also important (Table 1). The largest percentage of weed cover in 1985 was common lambsquarters (43 to 61%) and giant foxtail (28 to 36%). In 1986 carpetweed (13 to 29%), giant foxtail (12 to 26%), and yellow nutsedge (11 to 14%) covered the largest area.

Our findings agree with Roberts (10) who worked with snap beans (*Phaseolus vulgaris* L.) and found an average reduction of 20% in yield with short weeds during the entire growing season but 100% loss when tall weeds were allowed to remain during the entire season. He found that an onion (*Allium cepa* L.) crop could withstand weed growth for 5 wk but a total crop loss occurred when weeds were uncontrolled during the entire season. He also reported that 4 wk without weed removal in red beets (*Beta vulgaris* L.) caused extensive losses.

Our research indicates that in 1985 and 1986, when bell peppers have a weed-interference period for 43.2 or 37.4 d, pepper fruit number will be reduced 10%. A weed-interference period of 59 d reduced pepper fruit number 50%. When our research is compared to work by Weaver and Tan (14) on tomatoes, we agree that the longer the weed-interference period, the greater the reduction in fruit number.

Friesen (6) reported that when weeds in tomatoes were uncontrolled between 24 and 36 d after planting, a 50% yield reduction was observed. Singh et al. (12) found that when

weeds were uncontrolled, tomato yield reduction was 49 to 73% which was considerably lower than the 2-yr average yield reduction of 92% we found with bell peppers. Peppers are usually slower growing than tomatoes and are therefore less competitive with weeds (5). Labrada and Santos (9) found that a critical weed-interference period for tomatoes was in the first 30 to 40 d after transplanting. Our research with bell peppers compares favorably with these reports.

Table 1. Weed populations in bell peppers in 1985 and 1986 at Frederick, MD^a.

Weed species	Weed parameter			
	1985		1986	
	Mid-summer	Late summer	Mid-summer	Late summer
	plants 0.1 m^{-2}			
Total broadleaf weeds ^b	29	26	44	53
Total grasses	25	13	22	17
	% cover			
Carpetweed ^{b,c}	4	0	29	13
Common lambsquarters ^b	43	61	4	4
Common purslane ^b	5	0	6	6
Giant foxtail	28	36	12	26
Redroot pigweed ^{c,d}	13	1	13	9
Yellow nutsedge ^b	0	0	14	11
Yellow woodsorrel	2	0	6	8

^aMeans of eight plots without weed removal.

^bSignificant year effect at the 5% level as determined by analysis of variance.

^cSignificant time-of-year effect at the 5% level as determined by analysis of variance.

^dSignificant year by time-of-year interaction at the 5% level as determined by analysis of variance.

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Larry Douglass and the Consulting Service of USDA-ARS/University of Maryland provided statistical analyses, Sue Douglass provided the graphics, and Michelle Bowers, Greg Bures, Shelley Carter, Sarah Moser, Sandra Schwartz, Tracey Snell, and Teresa Stevens provided technical assistance in the field.

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Effects of Purple Nutsedge (*Cyperus rotundus*) on Tomato (*Lycopersicon esculentum*) and Bell Pepper (*Capsicum annuum*) Vegetative Growth and Fruit Yield¹

JOSE P. MORALES-PAYAN, BIELINSKI M. SANTOS, WILLIAM M. STALL, and THOMAS A. BEWICK²

Abstract: Additive series experiments were conducted under greenhouse conditions to determine the effect of season-long interference of different initial population densities of purple nutsedge on the shoot dry weight and fruit yield of tomato and bell pepper. Purple nutsedge densities up to 200 plants/m² linearly reduced shoot dry weight at flowering and fruit yield of both crops as weed density increased. Both variables were directly correlated, and for each percentage unit of tomato shoot dry weight loss at flowering, fruit yield was reduced 1.24 units, whereas for bell pepper this relationship was 1 to 2.01. Total shoot and tuber biomass of purple nutsedge increased as density increased. The presence of either crop caused a decline in the total shoot dry weight accumulation of purple nutsedge, with tomato producing a higher degree of loss than bell pepper to the weed. Fruit yield losses due to purple nutsedge interference reached 44% for tomato and 32% for bell pepper.

Nomenclature: Purple nutsedge, *Cyperus rotundus* L. # CYPRO; tomato, *Lycopersicon esculentum* Mill.; pepper, *Capsicum annuum* L.

Additional index words: Purple nutsedge competition, interference, dry matter reduction, fruit yield reduction.

Abbreviations: DAT, days after transplanting.

INTRODUCTION

Tomato and pepper are among the 10 most important vegetables in the U.S. The major leading fresh market production areas include Florida and California, where these two crops are grown throughout the year. In Florida during the 1995-1996 season, tomato and pepper accounted for almost 42% (ca. US \$660 million) of the overall value of vegetable production (USDA 1997).

Purple nutsedge is considered the worst weed in the world because of its widespread distribution and difficult control (Holm et al. 1991). This weed is commonly present in tomato and pepper fields in Florida, usually at densities exceeding 100 plants/m². Purple nutsedge interference has been known to reduce yields in a number of crops. For example, yield losses of cucumber (*Cucumis sativus* L.) and rice (*Oryza sativa* L.) resulting from purple nutsedge interference are reported to be 43% (Okafor and De Datta 1974, 1976; William and Warren 1975). Carrot (*Daucus carota* L.) and lettuce (*Lactuca sativa* L.) yield reductions have been as high as 50 and 54%, respectively (Morales-Payan et al. 1996; William

and Warren 1975). Yield losses of 70% in radish (*Raphanus sativus* L.) and 81% in beans (*Phaseolus vulgaris* L.) due to purple nutsedge interference have also been reported (Santos et al. 1996; William 1973).

In most cases, cultivation and other mechanical methods for nutsedge control in vegetables are neither practical nor economical, and selective herbicides providing satisfactory control of this weed in tomato and pepper fields are lacking (Stall et al. 1996). In Florida, methyl bromide has been used as an effective tool for early season control of purple nutsedge in tomato and pepper. However, because of environmental concerns, this product will be unavailable by the year 2001. In the absence of methyl bromide and selective herbicides for purple nutsedge control in tomato and pepper, this weed is significantly limiting the production of these vegetable crops.

Data on the extent of interference between a given crop and a weed are necessary to determine the importance of the weed in the system and to devise strategies for its management. Additive experiments are an important means to determine weed-crop interference. In this approach, weed density is varied while crop density remains constant (Cousens 1985, 1991; Radosevich 1987; Zimdahl 1980). Information on the extent of damage caused by purple nutsedge in most vegetables is scarce

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fragmentary. In the case of tomato and pepper, there are reports on the effect of the season-long interference of purple nutsedge at a single density under field conditions in Brazil (William and Warren 1975).

In tomato and other vegetable crops, the critical period of weed interference occurs before the reproductive stage of the crop is reached (Kasasian and Seeyave 1990), and reductions in plant growth should be detectable. Currently, there is no documentation on the effect of different population densities of purple nutsedge on the vegetative growth and yield of tomato and pepper. Moreover, a relationship between vegetative growth reduction and yield loss caused by nutsedge interference as a function of weed density has not been established. Because this information is lacking, the objectives of the studies were (1) to determine the effect on increasing purple nutsedge density on the vegetative dry matter production and yield of tomato and bell pepper when allowed to interfere until flowering and fruit production, and (2) to determine the relationship between vegetative dry matter and yield reduction under greenhouse conditions.

MATERIALS AND METHODS

Greenhouse studies were conducted at Gainesville, FL, between the winter of 1994 and the fall of 1995. Plants were grown under an 11-h photoperiod with average solar radiation at noon of $1,500 \mu\text{mol}/\text{m}^2/\text{sec}$ and day and night temperatures of $26.4 \pm 5^\circ\text{C}$. One seedling of either 'Sunny' tomato or 'Belle Star' bell pepper having two true leaves (about 10 cm tall) was transplanted in the center of a 20-L (32 by 30 cm) cylindrical plastic container filled with a potting medium composed of 50% vermiculite, 30% sphagnum peat, and 20% perlite. Viable purple nutsedge tubers from Gainesville, FL, weighing 0.5–0.75 g were transplanted in the containers the same day as tomato or pepper plants. Purple nutsedge tubers were distributed uniformly on the container surface area at densities equivalent to 0, 25, 50, 100, 150, or 200 plants/ m^2 . Soil was maintained close to field capacity by providing daily automatic drip irrigation. A full-strength Hoagland's solution dissolved in 10.5 L water was applied to each container weekly to minimize competition for mineral nutrients as determined in preliminary studies.

A completely randomized design with five replications per trial was used, in which the containers were the experimental units. Two sets of containers were established for each crop, one to be harvested at crop flowering and another to be harvested when tomato or pepper

fruits reached maximum growth, as determined by color break. Measured variables for tomato and pepper were total shoot dry matter at 40 d after transplanting (DAT) when all the plants were flowering, total shoot dry matter at 90 DAT after final fruit harvest, and fruit yield. Tomato and bell pepper total shoot dry weight losses were calculated as percentages of the weed-free control (0 nutsedge density). Purple nutsedge variables measured were total shoot dry weight, tuber number, and weight at either the flowering time of the crops or at the final fruit harvest.

Shoot dry matter production was obtained by drying the tissues for 2 d at 70°C . To determine the season-long interference, fruit harvesting began when fruits started to ripen and was continued for 15 d. Resulting data were analyzed for density effect by performing analysis of variance at the 5% significance level. The data from three trials were pooled because there were no treatment by trial interactions. Regression analysis was performed to characterize the relationship between densities and the measured variables.

RESULTS AND DISCUSSION

Tomato and bell pepper shoot dry weight at flowering was reduced significantly by purple nutsedge interference. A linear equation described the relationship between purple nutsedge density and shoot dry weight loss of both crops ($y = 0.0787x$, $r^2 = 0.99$ for bell pepper; $y = 0.1708x$, $r^2 = 0.98$ for tomato) at 40 DAT (Figures 1 and 2). As expressed by the regression slopes, tomato and bell pepper shoot dry weight losses were higher as purple nutsedge density increased. The effect of purple nutsedge on shoot dry weight loss was more pronounced on tomato than on bell pepper. However, when shoot dry weight of tomato and bell pepper was measured after final fruit harvest (90 DAT), there were no significant differences due to purple nutsedge densities (data not shown). This finding indicates that in the period between flowering and final fruit harvest (40 and 90 DAT, respectively, for tomato and bell pepper), there was compensation for the shoot dry weight loss caused by purple nutsedge interference that occurred between transplanting and flowering.

A linear relationship described the effect of purple nutsedge density on fruit yield of tomato and bell pepper ($y = 0.1582x$, $r^2 = 0.98$ for bell pepper; $y = 0.2182x$, $r^2 = 0.95$ for tomato) at 90 DAT (Figures 1 and 2). As purple nutsedge density increased, fruit yield declined in both crops. Yield loss was higher in tomato than in bell pepper at a given purple nutsedge density—as high as

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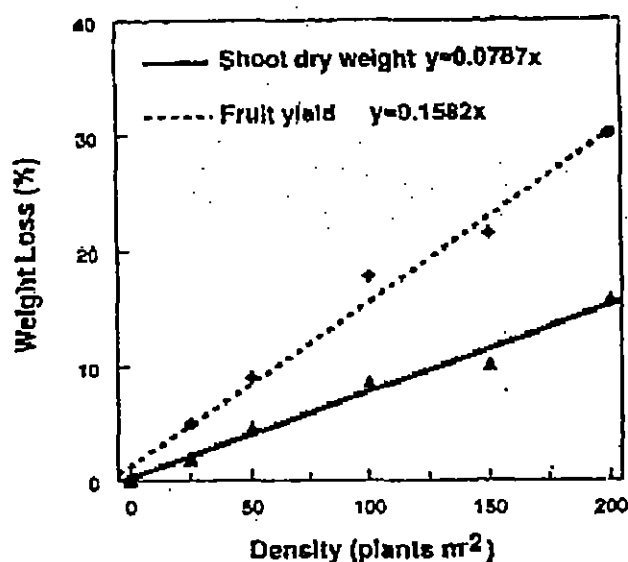


Figure 1. Bell pepper shoot dry weight at 40 DAT and fruit yield losses under different purple nutsedge densities (CYPRO). Values are averages of three experiments. Regression equations for tomato shoot dry weight: $y = 0.1708x$, $r^2 = 0.96$ and for fruit yield: $y = 0.2182x$, $r^2 = 0.95$.

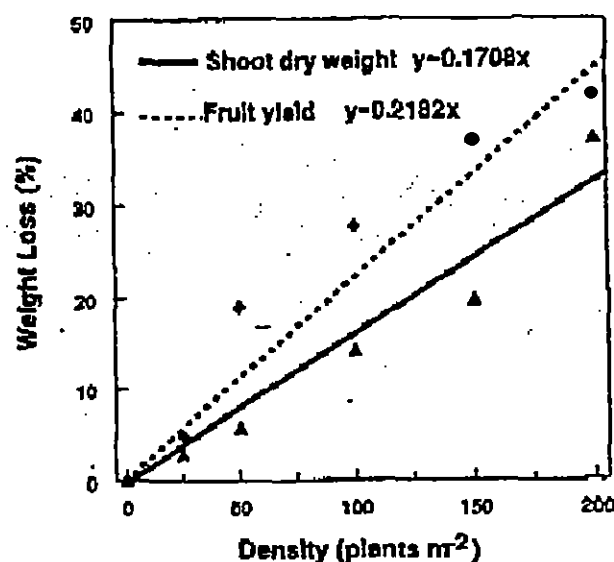


Figure 2. Tomato shoot dry weight at 40 DAT and fruit yield losses under different purple nutsedge densities (CYPRO). Values are averages of three experiments. Regression equations for bell pepper shoot dry weight: $y = 0.0787x$, $r^2 = 0.99$ and for fruit yield: $y = 0.1582x$, $r^2 = 0.98$.

44% for tomato and 32% for bell pepper at a purple nutsedge density of 200 plants/m². Similar reduction patterns have been found for purple nutsedge interference with a vegetable root crop such as radish (Santos et al. 1996), a leafy vegetable such as lettuce (Morales-Payan et al. 1996), and a cereal such as rice (Okafor and De Datta 1976).

In both tomato and bell pepper, the percentage of shoot dry weight loss at flowering (40 DAT) and the percentage of fruit yield loss (90 DAT) were significantly correlated. For tomato, the correlation coefficient (r) was 0.87, whereas for bell pepper it was 0.99, indicating a strong direct relationship between these two variables. For each percentage unit of tomato shoot dry weight loss, fruit yield was reduced 1.24 units. In bell pepper, a fruit yield loss of 2.01 percentage units was associated with each unit of shoot dry weight loss.

The fact that purple nutsedge densities caused significant effects on the shoot dry weight of both crops at flowering and that these differences were no longer present at final harvest suggest that after flowering, tomato and bell pepper plants dedicated more photosynthates to vegetative growth as purple nutsedge densities increased. This differential response of shoot dry matter accumulation in these crops could be attributed to the fact that tomato and bell pepper plants compensated for the delayed shoot dry matter accumulation caused by the increasing purple nutsedge interference, resulting in decreased supply of photosynthates dedicated to fruit pro-

duction, as reflected by the increasing yield loss in tomato and bell pepper.

Purple nutsedge density had a significant effect on the total tuber and shoot dry weight and tuber number of weed plants per area. As purple nutsedge density increased, so did shoot and tuber dry weight and tuber number, either in pure stands or in the presence of tomato or bell pepper. The same pattern of purple nutsedge shoot and tuber dry matter accumulation was present at crop flowering (40 DAT) and at final crop harvest (90 DAT), with higher values measured at final crop harvest.

The relationship between purple nutsedge density and total shoot dry weight was linear when the weed was grown in monoculture and also when tomato and bell pepper interfered with nutsedge. Tomato and bell pepper caused a significant reduction in purple nutsedge total shoot dry weight, with the effect of tomato being more pronounced, as described by the regression equations $y = 1.5057x$ for purple nutsedge alone, $y = 0.9267x$ with bell pepper, and $y = 0.4686x$ with tomato (Figure 3). Comparable results were obtained in greenhouse trials carried out in Brazil, in which increasing purple nutsedge densities significantly reduced corn (*Zea mays* L.) biomass, and corn presence significantly lowered nutsedge dry matter accumulation (Salvador 1986).

Individual weight of purple nutsedge tubers was not significantly influenced by the weed density, but it was lower when either tomato or bell pepper was present than when purple nutsedge was grown as a monoculture (data not shown). Purple nutsedge total tuber weight and num-

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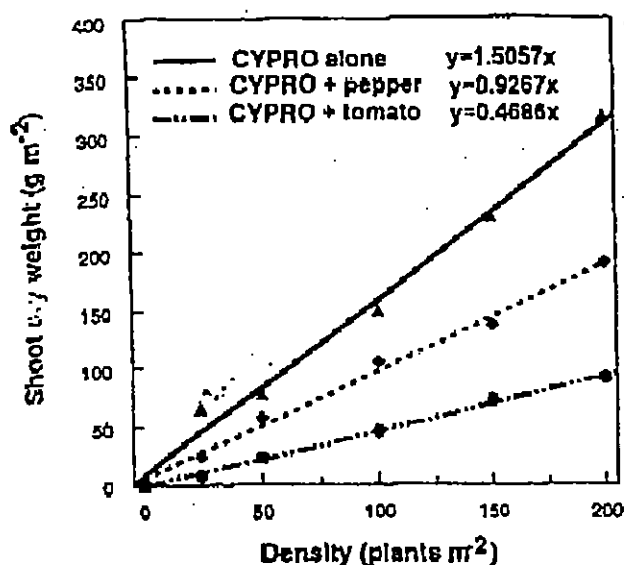


Figure 3. Purple nutsedge shoot dry weight in pure stands and mixed with either tomato or bell pepper at crop flowering under different purple nutsedge densities (CYPRO). Values are averages of three experiments. Regression equations for CYPRO alone: $y = 1.5057x$, $r^2 = 0.95$; for CYPRO–bell pepper mixtures: $y = 0.9267x$, $r^2 = 0.94$; and for CYPRO–tomato mixtures: $y = 0.4686x$, $r^2 = 0.91$.

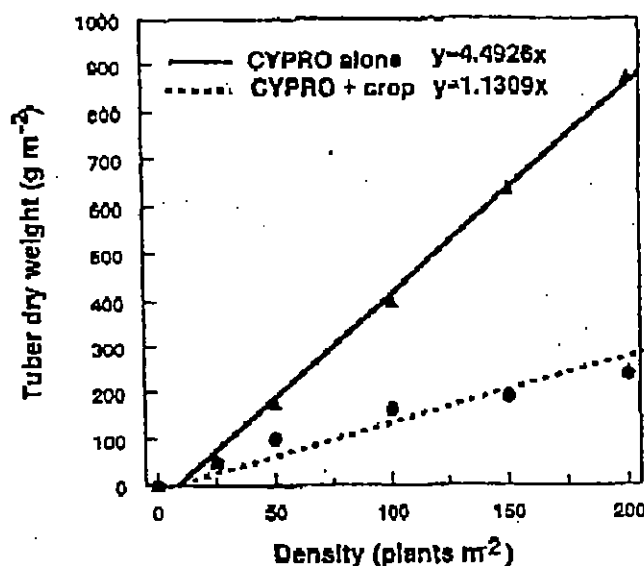


Figure 4. Purple nutsedge tuber dry weight in pure stands and mixed with either tomato or bell pepper at crop flowering under different purple nutsedge densities (CYPRO). Values are averages of three experiments. Regression equations for CYPRO alone: $y = 4.4926x$, $r^2 = 0.96$ and for CYPRO–crop mixtures: $y = 1.1309x$, $r^2 = 0.94$.

For per area increased linearly with increased weed density. Tuber production was more abundant when the weed was grown without crop interference than when tomato and bell pepper were present ($y = 4.4926x$ for purple nutsedge alone; $y = 1.1309x$ with either crop). However, purple nutsedge tuber production was not statistically different under tomato or bell pepper interference (Figure 4).

The effect of tomato interference in reducing purple nutsedge shoot dry weight was more drastic than that of bell pepper. This occurrence could be due to the difference in light interception by the canopy of tomato (72.5% radiation reduction) and bell pepper (38.6% radiation reduction) measured at 40 DAT, resulting in a diminished capability of purple nutsedge to accumulate shoot dry matter as shading by the crops increased. On the other hand, tuber dry weight was not significantly different when the weed interfered with tomato or bell pepper. This finding is attributed to the effect of increased shading on the dry matter partitioning of purple nutsedge. Previous research has shown that lower light availability reduced shoot dry weight and increased root and rhizome dry weight of purple nutsedge, while tuber dry weight remained unaffected (Santos et al. 1997b).

The major factors for interference between plants include competition for water, nutrients, space, and light and the production of allelopathic compounds. Because water and nutrients were supplied in nonlimiting

amounts, these two factors were not likely to have a major effect on the results. Tomato and pepper plants were taller than nutsedge (data not shown). Therefore, light interception by nutsedge plants may not have played a major role in the observed reductions of tomato and pepper shoot dry weight and yield.

In fact, it has previously been shown that light is one of the main competition factors in tomato–purple nutsedge interference relationships, with light interception by the tomato canopy significantly reducing the competitive ability of purple nutsedge (Santos et al. 1997a). Similar detrimental effects on purple nutsedge growth and competitiveness have been reported for other crops, such as sugarcane (*Saccharum* spp.) and alfalfa (*Medicago sativa* L.) that reduce light availability for nutsedge (Nel et al. 1976; Osgood et al. 1977). Tall tropical crops like banana (*Musa* spp.), cassava (*Manihot esculenta* Crantz), coffee (*Coffea arabica* L.), and cocoa (*Theobroma cacao* L.) produce dense canopies that deprive purple nutsedge of light and significantly suppress the growth of this weed.

The presence of tomato had a greater negative effect on purple nutsedge than the presence of bell pepper, probably because of more intense shading by tomato plants. In turn, shoot dry weight and yield reductions due to purple nutsedge interference were higher in tomato than in pepper. Purple nutsedge has been known to be allelopathic to a number of crops, including tomato (Gilreath 1981; Meissner et al. 1979). The mutually

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damaging relationship between interfering tomato and purple nutsedge could be explained by the shading effect of tomato, resulting in a decline of purple nutsedge shoot growth, imposing stress on the weed to the point of increasing its release of allelopathic compounds, which in turn decreased the productivity of tomato. Because both the effect of purple nutsedge on bell pepper and the effect of bell pepper on the weed were less severe than those observed in the tomato-purple nutsedge interference, a similar process may operate in the interference relationships of the two crops and purple nutsedge, but to a lesser extent of interspecific damage with bell pepper than with tomato.

The results of this study indicate that under greenhouse conditions, increasing purple nutsedge densities reduce shoot dry weight and yield significantly in both tomato and bell pepper. The difference in light interception by the canopies of the two crops, and thus the attenuated light incidence on nutsedge, could partially account for the differential effect of their presence on purple nutsedge shoot biomass production. Allelopathic effects and competition for space due to the presence of tomato or pepper could be possible mechanisms causing biomass reduction on purple nutsedge under the conditions of this study. A direct relationship was found between shoot dry weight reductions at flowering and fruit yield losses for both crops. Studies should be conducted that relate the results obtained in this research to tomato and pepper fruit yield and quality loss caused by increasing purple nutsedge population densities under field conditions.

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The Critical Period of Nutsedge Interference in Tomato

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Purple and yellow nutsedges (*Cyperus rotundus* L. and *Cyperus esculentus* L.) are considered the worst weeds in the world. Both species are found as weeds in vegetable crops in Florida. Nutsedges are problematic because of their difficulty of control, and their high capacity for and spread. The high rate of methyl bromide use in tomatoes is solely due to nutsedge control. Nutsedges also can emerge and penetrate through the polyethylene mulch when not in a conventional mulched bed situation. The reduction of methyl bromide use and pending loss of use cause nutsedge control in tomato production. Due to the lack of information on the negative impact of purple and yellow nutsedge on yield and quality of the crop, several studies were undertaken. The presented here is part of the results obtained from studies carried out over three years at several locations.

Materials and Methods

Depending on the study, either the Solar Set or the Solemor cultivar was used and grown in beds 32 inches on top, with an in-row spacing of 18 inches. To standardize the studies on irrigation was used, and monitored with irrometers. The crop was harvested three times a year according to Tomato Committee standards.

Beds were fumigated with MC-33 to control all pests. Tomato and sprouted nutsedge tubers were planted into the bed seven days after fumigation.

Additive Studies

The extent of weed interference with crops is density-dependent. No systematic data is available regarding the relationship between season-long interference of different nutsedge densities and yield losses. Such knowledge is vital in order to determine nutsedge density thresholds, below which suppressive (control) actions would be unnecessary, based on allowable yield losses due to interference.

Yellow nutsedge was planted in the beds at the same time as tomato at the populations of 0, 30, 40, 50, and 100 plants per square meter. Purple nutsedge tubers were planted at 0, 25, 50, 100 and 150 per square meter.

Tomato yield losses increased sharply as nutsedge densities increased from 0 to 50 plants/m² and 0-100 purple nutsedge plants/m² (9.3/ft²). Season long interference by yellow nutsedge caused a total marketable yield of tomato by 50%. Total marketable yield loss of tomatoes was as high as 100% with purple nutsedge. Marketable yield loss of 10% was seen at season long interference by a population of 25 plants/m² (2.3/ft²) for both the yellow and purple nutsedges.

The percent of yield loss was most dramatic in the medium sized tomato fruit from interference by both species. Purple nutsedge interference caused yield losses of 43% for Extra-Large fruit, 50% for Large sized fruit and 98% for medium sized fruit. Yellow nutsedge interference caused losses of 100% for Extra-Large sized fruit, 50% for Large and 75% for medium sized fruit. The yield losses were less from interference from yellow nutsedge than purple nutsedge, but the interference was

half as many plants per area.

Interference Influenced by Nitrogen Fertilization

Recommended N, P and K rates for tomato are relatively well established in Florida's pro. However, recommendations are generally based on weed-free nutrient rate studies, which are adequate when troublesome weeds are present in the field. Competition for nutrients has been recognized as an important factor in weed-crop interference relationships in other crops. There has been no experimental data regarding the effects of N rates on interference of nutsedge in tomato.

In these trials, N fertilizer was applied at 50, 100, 150, 200, 250, 300 and 350 kg/ha which is equivalent to 45, 90, 134, 180, 224, 268 and 312 lb/A. P and K were applied at soil test recommended rates. Interference with yellow nutsedge was at 50 plants/m² and purple nutsedge at 100 plants/m².

The best tomato yields were obtained at N rates of 200 to 250 kg/ha (180-224 lb/A) coinciding with recommended rates for Florida. Above these N rates, the number of X-Large and Large sized fruit declined while the number of medium sized fruit increased.

When the tomatoes were grown with either yellow or purple nutsedge interference, the percentage marketable yield loss was less influenced by the nutsedges at the recommended N rates (180-225 lb/A). Tomato was less competitive at N rates under 200 kg/h and the nutsedge was more competitive at the higher N rates.

Manipulating N rates does not seem to be an option. Using the recommended N rates for tomato yield is also the optimum N rate even if nutsedges are present.

The Critical Period of Interference

The duration of weed interference is of great importance in the outcome of the crop-weed competition. The season-long data reflects the maximum interference effects of nutsedges. The quantitative impact of nutsedge interference during periods of the crop growth would determine the percentage suppression necessary to avoid yield reductions above predetermined acceptable losses. The period of weed suppression necessary to avoid yield reductions (Critical Period of Interference) in separate studies are necessary. In these studies, the yellow nutsedge population was 50 plants/m² and the purple nutsedge population used was 100 plants/m². In the first study, the nutsedges were removed at either 1, 3, 5, 7, 9 or 11 weeks after transplanting. The yield from each removal date was then compared to no weed interference to determine the period of time that the nutsedges can compete with the crop before yield reduction occurs. In the second trial nutsedges were planted 1, 3, 5, 7, 9 or 11 weeks after establishment. In many instances, weeds may emerge later during the season and not be able to cause yield losses. This study would define that period. The time between the initial emergence of a weed does not cause yield reduction above a specified percentage and late in the season when a weed will no longer reduce yield if it emerges, is the time when the weed must be controlled, called the critical period.

The results of these studies show that in order to avoid tomato yield losses above 5%, the tomato must be kept purple nutsedge-free during the period of 2-10 weeks after transplanting. To avoid yield losses above 10%, purple nutsedge must be suppressed during the period of 3-6 weeks after transplanting.

For yellow nutsedge interference, tomato yield losses above 5% can be prevented by suppressing the weed during the period of 2 to 10 weeks after transplanting, whereas yield losses above 10% can be avoided by yellow nutsedge suppression during the period of 4 to 9 weeks after transplanting.

Summary

The studies conducted indicate that to reduce yield losses of tomatoes due to interference

and purple nutsedges, the grower should:

1. Reduce the population of nutsedge in the field to less than 25/m², 20/yard² or 2.3/ft² population less than 10% yield loss will be expected.
2. Grow the tomatoes under the optimum recommended nitrogen fertilizer rate. Over enhance the nutsedge competition while underfertilization will reduce the tomato p competitive ability.
3. Control the nutsedge in the bed, when possible, from 2 to 10 weeks after tomato t

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DETERMINATION OF SUMMER SQUASH'S TOLERANCE TO WEED
INTERFERENCE: A CRITICAL PERIOD STUDY

Sister Jeanne-Yolaine Mallet, Richard A. Ashley^{1/}

ABSTRACT

Yellow squash (*Cucurbita pepo* L.) c.v. 'Early Prolific' was grown on a Gloucester very stony sandy loam, 3 to 5% slope, uncultivated before the experiment. Seeds were planted June 5, 1987. Squash was maintained weed free or allowed to compete with weeds for 3, 6, 9 or 12 weeks after planting. Squash was harvested from July 23 to August 22. Number and weight of fruit was recorded. Effects of weed-removal treatments on the yield were significant. Critical period of weed interference based on the yield of squash occurred during weeks 4 through 6. There was no significant difference between treatments where squash was kept weed free during this 3 week period.

INTRODUCTION

While all crops can withstand weed competition for some duration, the question is to determine when the yield-reducing competition is likely to occur (3). The specific minimum period of time during which the crop must be free of weeds in order to prevent loss in yields is referred to as the critical period. It represents the overlap of two separate components: the length of time weeds can remain in a crop before interference begins and the length of time that weed emergence must be prevented so that subsequent weed growth does not reduce the crop's yield (20). The critical period varies greatly with relative growth rates of a crop and its associated weeds (15, 16, 20), the environment (11, 14, 16), and cultural practices such as row spacing (4, 6, 14).

The critical period has been determined for a variety of crops: 3 or more weeks after planting for soybeans (5, 15); 5 to 7 weeks for field beans (7); 4 weeks after cotton emergence when competing with Johnsongrass (2), 2 to 6 weeks with yellow nutsedge (12) but more than 8 weeks with common cocklebur (18); and 12 to 36 days after cucumber emergence (8). While beans require only a 4 week weed free period, garlic needs 13 weeks (11). This last example illustrates that the duration of the critical period is closely related to the efficiency with which plants intercept light.

Results differ considerably from crop to crop and there seems to be little information on summer squash's competitive ability. The present experiment was designed to determine the critical period of weed interference with summer squash.

MATERIALS AND METHODS

The experiment was conducted in 1987 in Bethlehem, CT, on a Gloucester very stony, sandy loam with a 3 to 5% slope. This series developed on

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riable to very firm glacial till, well drained or moderately well drained. Its permeability is moderate to moderately rapid in the surface layer and subsoil. Before the experiment the area was uncultivated and mainly infested by quackgrass (Agropyron repens (L.) Beauv.), common milkweed (Asclepias syriaca L.), horse nettle (Solanum carolinense L.) and groundnut (Apios americana Medic).

The experimental area was cleared, plowed and rocks removed by hand. Fertilizer was applied according to soil test recommendations and disked in prior to sowing.

Individual plots consisted of 3 rows, 4.6 m long with 0.9 m between rows and 46 cm between plants within rows. Seeds of straight neck Yellow Squash (Cucurbita pepo L.) cv 'Early Prolific' were planted June 5, 1987. Seeds were covered with a mixture of four parts soil from the plot, two parts peat and one part vermiculite.

4.14 ² ₂

Treatments were arranged in a randomized complete block design with three replications. Weed-removal treatments were as follows. Weeds were removed for 3, 6 and 9 weeks after seeding after which weeds were allowed to grow (treatments 1, 2, 3 respectively). Weeds were allowed to grow for 3, 6 and 9 weeks after seeding after which weeds were removed and kept weed free (treatments 5, 6, 7 respectively). In treatment 4, plots were kept weed free throughout the season while in treatment 8, plots were weed infested throughout the season. (Table 1)

Weeds were removed by hand pulling and hoeing. Milkweed was removed as it emerged in every plot because of its possible allelopathic effect on crops (15). Weed density was taken at random at the end of the sixth week prior to applying treatment 6. Weeds were hand pulled, sorted by species, counted and weighed in the field. Quackgrass was the predominant weed with a density of 209 shoots/m². Other weeds present throughout the experimental area were: lambsquarter (Chenopodium album L.) (density of 29 shoots/m²), ragweed (Ambrosia artemisiifolia L.) (density of 14 shoots/m²) and groundnut (density of 22 shoots/m²). Insect control practices were applied as required.

Squash were hand harvested fourteen times from July 23, to August 22, 1987. Number and weight of fruit were recorded. Data was taken from the center row of each plot and from the center 3 meters of the row.

$$4.14 \text{ m}^2 \times \frac{10000 \text{ m}^2}{\text{ha}}$$

RESULTS AND DISCUSSION

Table 1. Effect of weed free period on yield of summer squash

Treatment n ^o	Treatment	Squash Yield Per Plot
		kg
1.	Weed free week 0-3 weedy week 4-12	8.59
2.	Weed free week 0-6 weedy week 7-12	12.68
3.	Weed free week 0-9 weedy week 10-12	11.59
4.	Weed free week 0-12	14.18
5.	Weed free week 4-12 weedy week 0-3	13.41
6.	Weed free week 7-12 weedy week 0-6	10.27
7.	Weed free week 10-12 weedy week 0-9	9.64
8.	weedy week 0-12	7.27
LSD 5%		2.9

The yield was significantly greater in all treatments where plots were maintained weed-free during the weeks 4 to 6 (Treatments 2, 3, 4 and 5). There was no significant difference between treatments kept weed-free for 6 weeks (T.2), 9 weeks (T.3) and throughout the season (T.4) and treatments weed-infested for the first three weeks and then weeded (T.5). Therefore the actual yield reducing competition occurred in that period of time which corresponded, in the squash life cycle, to flower bud formation starting at the end of the fourth week and the opening of the first flowers during the sixth week. When weeds were not interfering during the critical period, yield was not significantly reduced. This finding seems to support Radosevich's statement (16): "The critical period during which competition occurs and crop yield reductions result may be a certain number of weeks after emergence. However, it is more likely that this critical period relates to particular stages of weed and crop development which are relative to one another". This would respond to Weaver's concern that (18): "the variability of crop and weed growth rates from year to year limits the practical value of the critical period concept". But if the critical period was determined also in relation to the growth cycle of a given crop, it could increase its practical value. Although this experiment does not allow to conclude absolutely this relation between life-cycle and critical period of interference, it seems that more research in that direction would be beneficial.

Squash not competing with weeds during the critical period (T. 2, 3, 4, 5) not only produced more total yield but also an earlier yield than the other treatments, suggesting that weed interference during the critical period delayed flowering.

Although Bleasdale (1) says that "the presence or absence of weeds during the first few weeks of a crop's growth is critical in determining the ultimate yield", it has been reported that the critical period for tomatoes was between the fifth and ninth weeks after seeding (20). The results obtained with squash support this finding. The critical period occurred

luring weeks 4 through 6 and there was no significant difference between treatments constantly weed infested (T.8) and treatments weeded only for the first three weeks (T.1) (Table 1). On the contrary, when squash were allowed to compete with the weeds only for the first three weeks (T.5), the yield was not reduced and was 60.6% greater than yield produced by squash weed-free for the same first three weeks (T.1).

There was no significant difference between the yield produced by squash weed-free for either the 3 weeks preceeding the critical period (T.1) or for the 6 weeks (T.6) and 9 weeks (T.7) following it. Yield when the plot was constantly kept weed-free (T.4) was twice the yield produced by squash weed infested throughout the season (T.8).

The normal row-spacing for summer squash is 1.2 to 1.5 m. The row spacing used in this experiment (0.9 m) likely increased the competitive ability of squash. Many experiments (4, 9, 10, 14, 19) have concluded that narrow-row cultural practices enhance crop competitiveness, resulting in less weed growth and shorter weed-free requirement for maximum crop yield.

The effects of shading on quackgrass as reported by Williams (21) are a reduction of the shoot, rhizome, total dry weight and a lack of flowering. In this experiment, quackgrass was not observed to produce seed heads indicating that close row spacing of squash might produce a shading effect even when weeds were not controlled. Quackgrass was the predominant weed (65% of the total weed-stand) and few broadleaved weeds emerged where quackgrass was never removed. However, broadleaved weeds emerged after the application of the first and second treatments. The allelopathic potential of quackgrass as reported by Rice (17) could explain the absence of broadleaved weeds.

CONCLUSION

Summer squash grown at 0.9 m row-spacing can tolerate weed interference for most of the growing season, without a yield reduction, if weeds are controlled during the fourth through sixth week.

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Weed Interference in Pickling Cucumbers (*Cucumis sativus*)¹

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Abstract. In field experiments during 1975 to 1977 the final yield of cucumbers (*Cucumis sativus* L. 'Salty') was unaffected when a naturally occurring weed infestation remained in the plots for the first 12 days after emergence in 1975 and for the first 24 days in 1976 and 1977, provided the crop was kept weed-free subsequently. If the cucumbers were kept weed-free for the first 12 days after emergence in 1975, 24 days after emergence in 1976, and 36 days after emergence in 1977, there was no loss of yield caused by weeds that emerged later in the season. The critical period of weed interference was therefore between 12 and 36 days after crop emergence. In other experiments, cucumber yields were reduced significantly when only 5% of the weeds were allowed to remain in the plots longer than 24 days after crop emergence. The percentage of various commercial grades, based on cucumber size, was not altered by weed interference and appeared to be dependent on harvesting frequency.

Additional index words. Competition, interaction, allelopathy, yield, quality.

INTRODUCTION

Pickling cucumbers are an important cash crop in Canada with about 3700 ha grown annually, producing a crop valued at over \$10 million (12). Although several herbicides are recommended for use in cucumbers, these are only partially effective on weed species common to southern Ontario (9). In actual practice, most fields receive at least one supplemental hand weeding and inter-row cultivation. The timing of these operations may be important since early interference from even a few surviving weeds may reduce potential cucumber yields.

In a survey of the literature on weed interference in vegetable crops, published work on cucumbers, or any other vine crop, was found to be very limited. Data obtained before 1975 from unsprayed control plots of herbicide trials in southern Ontario however, indicate that cucumbers are very susceptible to weed competition (10, 11). In Brazil, it was found that 160 purple nutsedge (*Cyperus rotundus* L.) plants/0.1 m² reduced the yield of cucumbers by 43% and the critical period for nutsedge competition was 3 to 7 weeks after planting (13). In addition to direct competition for light, nutrients and moisture, there may be interactions involving toxic substances released from some weeds that inhibit cucumber growth and development (6, 7).

Information on the interference from naturally occurring weed species in field sown vegetable crops such as cucumbers is required to formulate practical procedures for chemical and

cultural weed control. The studies reported here were conducted to determine the critical period of weed interference in field sown pickling cucumbers, the effect of partial weed control on final cucumber yields and the effect of natural weed infestations on cucumber quality as measured by commercial grades of the harvested crop.

MATERIALS AND METHODS

Experiments were conducted at the Harrow Research Station from 1975 to 1977, inclusive. The soil is described as a Fox sandy loam having 70% sand, 16% silt, 14% clay, 1.1% organic matter, and a pH of 6.5 to 6.7. The crop was seeded on June 12, June 8, and June 3 in 1975, 1976 and 1977 respectively, in single row plots 8 m long and spaced 2 m apart. Each year the crop received 672 kg/ha N-P-K fertilizer (10-20-20) at time of seeding and was side dressed with 74 kg/ha ammonium nitrate about one month after crop emergence. The plots were irrigated with 25 mm water at least once during each summer to maintain normal crop growth. The cucumbers were hand-harvested at 1 week intervals beginning in mid July of each year. Four harvests were made in 1975 and 1976 and three in 1977. Naturally occurring weeds in the experimental area consisted primarily of common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.) and longspine sandbur [*Cenchrus longispinus* (Hack.) Fern.] at an average density of 190 plants/m². The above species accounted for over 90% of the weed cover at harvest.

Critical period of weed interference. Two series of weed removal treatments were included. In the first series, plots were kept free of weeds by hand weeding for 12, 24, 36, 48, and 60 days after crop emergence. The weeds were subsequently allowed to develop until final harvest when they were removed and fresh weights recorded. In the second series, weeds were allowed to develop for periods of 12, 24, 36, 48, and 60 days after crop emergence, then the plots were weeded by hand and kept weed-free until harvest. Control plots were kept free of weeds or left weedy throughout the growth period. Treatments were replicated 6 times in a randomized block design.

Effect of weed density. In 1975 and 1976, the effect of interference from various weed densities was investigated. Weeds were allowed to emerge and develop for 24 days, at which time they were counted and thinned to 100, 50, 25, 10, 5 and 0% of their original density. This was accomplished by using a quadrant divided into 10 cm² sections and removing all the weeds from the appropriate number of sections, at random. In 1975, the surviving weeds represented a composite of the three species infesting the experimental area, while in 1976 all weeds, except common lambsquarters, were removed. Common lambsquarters was then thinned to the desired level using the quadrant method described above. In 1975, weeds were allowed to develop in, or were removed from the entire

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plot area, while in 1976 the common lambsquarters was confined to an area 15 cm on each side of the crop row. Treatments were replicated 6 times in a Latin square design.

Effect of weed interference on cucumber grades. Cucumbers harvested from the "critical period of interference" experiments were graded on a commercial grading machine according to shape and thickness. Commercial grades established in Canada for pickling cucumbers by diameter are 1: <2.5 cm; 2: 2.5 to 3.2 cm; 3: 3.2 to 4.1 cm; 4: 4.1 to 5.1 cm; and 5: >5.1 cm. Market prices in 1977 ranged from \$382.00/t for grade 1 to \$42.10/t for grade 5.

RESULTS AND DISCUSSION

Critical period of weed interference. In 1975, the yields were not greatly different for the various weed-free treatments, suggesting that keeping the plots free of weeds for the first 12 days after crop emergence was almost as effective in maintaining crop yields as complete weed removal until final harvest (Table 1). The majority of the weeds emerged during this early period and by keeping the plots weed-free even for the first 12 days after crop emergence, high crop yields resulted. In 1976 and 1977, weed emergence continued for at least 12 and 24 days after cucumber emergence and it was necessary to keep cucumbers free of weeds for 24 to 36 days respectively, to maintain maximum crop yields.

When weeds were allowed to remain in the plots for more than 24 days after crop emergence in 1975 and 1976, and for more than 36 days in 1977, crop yields were reduced drastically. The cucumber plants in treatments where weeds were removed after these times, showed very little recovery after the weeds had been removed and yields at harvest were almost as low as when weeds were not removed at all.

Although the results were not consistent from year to year, the 3-yr means suggest that there was a critical period of weed interference somewhere between 12 and 36 days after cucumber emergence (Table 1). As already indicated for other crops, the exact critical period may depend on the relative time of crop and weed emergence (2, 5, 8).

The observation of this critical period of weed interference is of practical importance to cucumber growers from the standpoint of herbicide use and tillage practices. An appropriate herbicide would appear to be a pre-planting or pre-emergence type with a 24- to 36-day residual period. This would prevent establishment of the early germinating weeds which proved very damaging to young cucumber seedlings. A post-emergence herbicide, if used alone, would have to be applied within 24 days of crop emergence. There is no post-emergence herbicide available with adequate selectivity which can be used at such an early stage of cucumber development.

Effect of weed density. In both years cucumber yields were reduced by almost 50%, even when 95% of the weeds were removed 24 days after crop emergence (Table 2). In 1975, when the surviving weeds represented a composite of several species, crop yields continued to decline as the percentage of weeds remaining increased. In 1976, when common lambsquarters was the only weed present there was no significant difference in crop yield between 95% or 50% weed removal. Only when there was no removal of common lambsquarters was there a further drop in cucumber yields. The results indicate that cucumbers are very sensitive to interference from relatively low densities of common lambsquarters, suggesting a possible allelopathic effect similar to giant foxtail (*Setaria faberi* Herrm.) interference in corn (*Zea mays* L.) (1). Similar results have also been reported on common flax (*Linum usitatissimum*).

Table 1. Effect of time of weed removal on the yield of Salty pickling cucumbers grown on sandy loam soil, 1975 to 1977.

Duration of interference (days)	Weed weights ^a at harvest	Cucumber yields ^b			Mean ^c (%)
		1975	1976	1977	
		(t/ha)			
<i>Weed free</i>					
12	6.5 b	10.7 bc	7.8 de	4.6 de	67
24	1.1 c	10.1 bc	8.8 cde	2.9 ef	65
36	0.0 d	14.2 a	9.2 bed	11.2 a	103
48	0.0 d	12.1 ab	11.8 abc	9.2 abc	98
60	0.0 d	12.2 ab	11.4 abc	10.7 ab	102
to harvest	0.0 d	12.6 ab	10.8 abc	10.2 ab	100
<i>Weed infested</i>					
12	0.0 d	10.7 bc	12.8 a	7.9 bc	93
24	0.0 d	8.3 c	12.2 ab	10.4 ab	92
36	0.0 d	2.2 d	6.0 e	6.3 cd	43
48	20.0 a	1.5 d	2.8 f	0.3 f	13
60	18.2 a	1.3 d	1.8 f	0.1 f	10
to harvest	20.2 a	0.8 d	0.2 f	0.1 f	3

^aWeed weights recorded just prior to cucumber harvest. Weights are the average for 3 yr.

^bYields followed by the same letter in each year are not significantly different at the 5% level according to Duncan's multiple range test.

^cMean cucumber yield as percent of that obtained in plots kept weed-free until harvest.

Table 2. Effect of various weed densities on the yield of pickling cucumbers grown on sandy loam soil, 1975 to 1976.

Weeds removed (%)	Weed count ^a		Weed weights at harvest	Cucumber yields ^b	
	Initial	Final		1975	1976
	—(No/m ²)—			—(t/ha)—	
100	191	0	0.0	14.2 a	13.2 a
95	210	9	11.2	7.6 b	7.6 b
90	220	18	11.7	5.0 c	7.6 b
75	148	46	13.5	3.0 cd	6.4 b
50	195	98	14.0	2.8 cd	7.2 b
0	191	209	18.2	1.2 d	1.4 c

^aWeed counts are for 1975 only and represent a composite of common lambsquarters, common ragweed and longspine sandbur. In 1976, the only surviving weed was common lambsquarters at an initial count of 60/m².

^bYields followed by the same letter within each year are not significantly different at the 5% level according to Duncan's multiple range test.

simum L.), which has been described as a poor competitor with wild oats (*Avena fatua* L.) and wild mustard [*Brassica kaber* (DC.) L. C. Wheeler var. *pinnatifida* (Stokes) L. C. Wheeler] (3, 4). Further research is underway to determine the relative competitive influence of weed species occurring naturally in the experimental area and, if possible, to isolate the ecophysiological mechanisms causing such severe yield reductions in cucumbers.

Table 3. Effect of time of weed removal on the commercial grades of pickling cucumbers, 1975-77.

Duration competition (days)	Commercial grades in harvested crop ^a				
	1	2	3	4	5
	<2.54	2.54-3.18	3.18-4.13	4.13-5.08	>5.08
	—(%)—				
Weed free					
12	9.6	11.7	33.2	32.1	13.4
24	7.2	9.8	31.4	34.1	17.5
36	5.8	6.7	28.3	36.2	23.0
48	10.0	12.6	30.6	31.5	15.3
60	11.0	20.5	17.9	30.1	10.5
to harvest	9.8	10.6	35.0	35.9	8.7
Weed infested					
12	7.2	8.6	29.9	32.7	21.6
24	7.9	9.7	30.8	34.7	16.9
36	9.3	10.4	37.7	26.6	16.0
48	16.9	13.5	31.9	31.8	5.9
60	14.1	12.4	39.4	25.4	8.7
to harvest	13.9	11.2	38.5	23.5	12.9

^aCross-section (thickness) of cucumber in cm.

Effect of weed interference on cucumber grades. There were some notable differences in the percentage of each cucumber grade between various treatments (Table 3). Keeping the crop weed free for 24 to 36 days after emergence resulted in a low percentage of grades 1 and 2, and a high percentage of number 5; suggesting rapid growth and development of the crop. Allowing the crop to be weed infested from emergence to 48 days after emergence or longer, a high percentage of small cucumbers and a low percentage of large cucumbers resulted; indicating retarded growth and development. However, since commercial grades are based on size only, the percentage of each size would be influenced more by frequency of harvest than by agronomic practices or weed interference. If once-over destructive harvest is practiced, however, then weed interference would influence the proportion of various cucumber sizes.

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Weed competition in muskmelon and its effects on yield and fruit quality

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ABSTRACT. Field studies were conducted at Newe Ya'ar (northern Israel) during 1986 and 1988 to examine the critical period of weed competition in muskmelon (*Cucumis melo* L. cv. Galia). The yield of the control (weed free throughout the season) in 1988 was 45% higher than in 1986. In 1988, weed control was required within 6 weeks after seedling emergence in order to maintain fruit quality. Total yield was reduced significantly only if weeding started 7 weeks after emergence or later. Muskmelon remained competitive and maintained optimal yield potential if kept weed free during the first month of crop growth. The critical period for weed control in muskmelon was at the initiation of the rapid fresh-weight accumulation of the weeds and the pistillate flowering peak of the crop. Under Newe Ya'ar conditions this occurred 4-6 weeks after emergence of the crop.

KEYWORDS: *Cucumis melo* L; critical competition period; herbicide; weed control

Introduction

Although technological advances have been made in chemical weed control, herbicides for cultural management of cucurbit crops are often ineffective. Because of economic considerations, chemical companies do not produce specific herbicides for cucurbits. Among the herbicides approved for use in Israel, chloramben (Amiben) and bensulide (Prefar) are most suitable for cucumber production, and ethalfluralin (Sonolan) for melons. However, growers using these herbicides often encounter problems due to marginal crop safety and diverse cultivar response (S. Graf, personal communication, 1988). Climatic and soil interactions increase the difficulties in predicting herbicide response. The lack of herbicide efficacy limits large plantings of cucurbits in Israel. In many cases, cucurbits grown on small farms are still weeded by hand.

The critical period of weed competition in crop production is the minimum length of time during which weeds must be depressed in order to avoid yield reduction (Nieto, Brondo and Gonzalez, 1968). This period is the interval between the time a crop must be weed free after seeding (so that later emerging weeds will not cause yield losses) and the time in which weeds which have emerged with the crop may remain without causing yield losses. Removal of weeds during this interval will optimize crop yield.

In tomatoes, a single weeding 28-35 days after transplanting was effective in preventing yield decline in Canada (Weaver and Tan, 1983). The critical period of weed competition in this crop was determined as falling between 24 and 36 days after transplanting in Puerto Rico (Lugo, Liu and Almodovar, 1988). In cucumber, the critical period

of weed interference was between 12 and 36 days after crop emergence (Friesen, 1978) and the most effective time to remove the weeds was 3-4 weeks after seeding (Weaver, 1984).

In muskmelon, as in other dessert fruits, quality is often more important than yield. Among those characters in melon contributing to high fruit and yield quality are high total soluble solids (TSS), a full netted skin (in the cantaloupe group), a range of fruit sizes (depending on consumers' demand), and early season maturation of disease-free fruits.

The present study was conducted to determine the critical period of competition between weeds and muskmelon, and the effects of this competition on yield and fruit quality characteristics.

Materials and methods

Two field experiments were conducted at Newe Ya'ar Experiment Station (northern Israel) in the spring seasons of 1986 and 1988. Soil characters in this location have been described in a previous paper (Giskin and Nerson, 1984). In each experiment a plot of Galia (Karchi and Govers, 1977) melon was sown in mid-April on raised beds 2 m wide. There were two plants per hill and hills were spaced 0.5 m apart (20 000 plants/ha). Standard cultural practices, including drip fertigation (irrigation/fertilizer application) were employed.

Eight and ten weed-melon competition treatments were examined in 1986 and 1988, respectively. In 1986, plots were kept weed free for 3, 6 and 9 weeks after crop emergence, after which weeds were allowed to grow until harvest. In other plots, weeds were allowed to grow for 3, 6 and 9 weeks, after which they were removed and the plots were kept weed free

which weeds were allowed to grow until harvest. In other plots, weeds were allowed to grow for 4, 6, 7, 8 and 10 weeks, after which they were removed and the plots were kept weed free until harvest. In both experiments, two control treatments were used: (1) weed free the entire season, and (2) fully competitive (in which weeds were allowed to grow the entire season). Plots were hand-weeded once a week starting at crop emergence, with minimal soil and crop disturbance. Five replicates of 10 m² in 1986 and four replicates of 14 m² in 1988 were arranged in a randomized block design.

Five weed samples, 1 m² each, 3, 6 and 9 weeks after emergence in 1986 and four weed samples 4, 6, 7, 8 and 10 weeks after emergence in 1988, were taken to determine weed species, infestation and fresh-matter accumulation. In both experiments fruit was harvested throughout the month of July, three pickings per week, in a 2,2,3-day schedule. Each fruit was picked at the half-slip stage, weighed, rated for netting (on a scale of 0-5, where 0 = smooth and 5 = fully netted) and evaluated for disease symptoms. Netting index per plot was calculated as follows: $I = \sum_{i=1}^n (N \cdot W/Y)$, where I = netting index, n = fruits per plot, N = individual netting rate, W = individual fruit weight and Y = total yield per plot. At peak harvest of each plot, five fruits were selected for determination of TSS using an Atago digital refractometer. Data of each experiment were subjected to variance analysis and differences are presented by LSDs.

Results and discussion

In both years two species of *Amaranthus* accounted

the number of weed plants/m² in both experiments ranged between 30 and 90, in >80% of the plots the range was between 50 and 60. The fresh-weight accumulation of the weeds corresponding to the crop developmental stages is presented in Figure 1. Weed exponential rapid growth started 3-4 weeks after muskmelon emergence (beginning of staminate flowering). Keeping the plots weed free only 3-4 weeks after crop emergence, or allowing the weeds to infest plots no longer than this period, did not result in any detectable yield losses (Table 1). A significant reduction in yields occurred if weeding

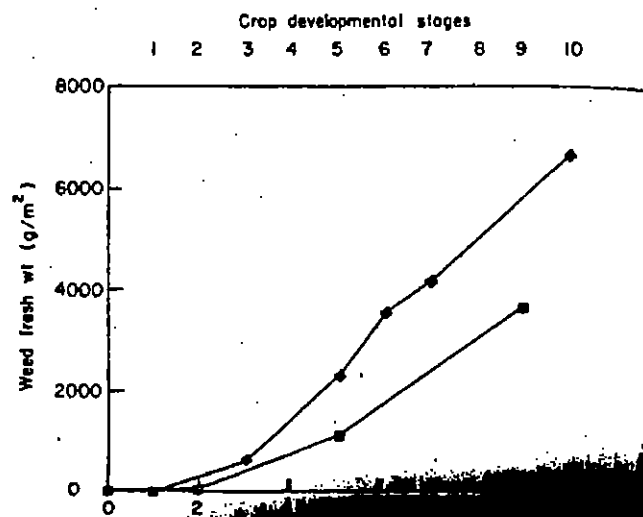


FIGURE 1. Weed fresh weight accumulation in muskmelon plots during the growing season (1986 and 1988). The lines represent the mean values of the netting index (0-5) for the 1986 and 1988 experiments.

TABLE 1. Effects of weed-free and weed-infested periods after crop emergence on yield and yield components in muskmelon (Newe Ya'ar 1986, 1988)

Treatment		Fruits (no./10 m ²)		Mean fruit wt (g)		Yield (kg/10 m ²)	
		1986	1988	1986	1988	1986	1988
Weed free	all season	29.5	40.4	1170	1235	34.3	49.6
	10 weeks		40.2		1297		52.2
	9 weeks	29.0		1212		35.0	
	8 weeks		38.5		1327		51.6
	7 weeks		39.3		1318		51.6
	6 weeks	29.8	37.7	1335	1358	40.0	51.3
	4 weeks		39.6		1383		55.2
	3 weeks	28.4		1060		30.1	
Weed infested	3 weeks	30.8		1115		34.4	
	4 weeks		39.1		1345		52.4
	6 weeks	26.0	35.2	1222	1228	31.6	43.3
	7 weeks		27.1		1222		33.3
	8 weeks		24.3		1007		25.0
	9 weeks	18.2		914		16.4	
	10 weeks		15.9		918		17.7
	all season	15.5	15.5	826	852	12.7	15.1
LSD (P = 0.05)		4.1	6.2	182	171	5.4	7.6

was initiated later than 6 weeks after muskmelon emergence. The 1988 data (Table 1) demonstrate that fruit-set (no./unit area) was reduced by weed interference earlier than fruit enlargement (final fruit weight). The rapid weed growth 7 weeks after emergence (Figure 1) probably limited the bees' ability to pollinate the crop, thereby resulting in a reduction of fruit number, while fruit weight remained unaffected. Later (from 8 weeks onward), weed competition reduced fruit weight also, but to a lesser extent than fruit number. The yield of plots kept weed free for only 6 weeks was higher than that of the whole-season weed-free control in 1986. A similar tendency was observed in 1988 as well as in earlier reports on cucumber and tomato (Friesen, 1978, 1979), and it is probably the result of the negative effect on fruit enlargement of frequent weeding in control plots. Weed-free control plots yielded 2.7 and 3.3 times that of weed-infested control plots in 1986 and 1988, respectively. These differences were mediated by a great effect on fruit number (1.9–2.6 times) and a smaller effect on fruit size (1.4 times).

Keeping the plots weed free for only 3–4 weeks after muskmelon emergence, or allowing the weeds to infest the plots no longer than this period, was sufficient to maintain most fruit quality characters (except earliness in 1988) (Table 2). Initiation of weeding 6 weeks after crop emergence, although not reducing the yield significantly (Table 1), did reduce earliness in both years and marketable yield, netting and TSS in 1988 (Table 2). It is concluded that quality characters (mainly earliness) are more sensitive and more easily damaged by weed competition than are the yield and yield components.

Delaying weed removal until fruit development and maturation stages (7–10 weeks after emergence) had marked negative effects on all quality characters tested.

The present data suggest that the critical period of weed-melon competition under local conditions in the spring is between 4 and 6 weeks after crop emergence. At this time the crop is in the anthesis-fruit-set stage, which corresponds to rapid weed fresh-weight accumulation. This developmental stage may be critical also under other field conditions, as the main negative effect of weed competition is exerted on fruit-setting and, consequently, on number of mature fruits. A single weeding during the critical period, preferably at the beginning of this phase, will probably be enough to maintain yield potential and fruit quality. Keeping the field weed free during the first 3–4 weeks may be an alternative means of control, because weeds that will emerge later cannot compete successfully with the growing melon plants.

The determination of the critical weed-melon competition period is significant for current herbicide technology. A pre-emergence herbicide with ability to delay weed emergence no more than 3–4 weeks may be useful in a melon field. Likewise, herbicides possessing marginal selectivity could be useful in post-emergence applications as late as at melon anthesis (when weeds had not caused irreversible crop damage). In such a case, melon plants would have a better chance of recovery.

Note

Contribution from the Agricultural Research Or-

TABLE 2. Effects of weed-free and weed-infested periods after crop emergence on fruit quality characteristics in muskmelon (Newe Ya'ar 1986, 1988)

Treatment		Marketable yield (%) ^a		Early yield (%) ^b		Netting index ^c		TSS ^d	
		1986	1988	1986	1988	1986	1988	1986	1988
Weed free	all season	63	78	27	74	3.0	3.8	10.2	11.9
	10 weeks		82		78		3.8		13.0
	9 weeks	74		27		3.5		11.0	
	8 weeks		75		74		3.7		11.8
	7 weeks		82		77		3.9		13.4
	6 weeks	68	86	31	76	3.5	4.2	11.1	13.4
	4 weeks		82		70		3.9		13.7
	3 weeks	58		30		3.0		9.8	
Weed infested	3 weeks	69		24		3.3		10.7	
	4 weeks		75		62		3.6		12.8
	6 weeks	66	64	16	11	3.3	3.0	11.1	10.1
	7 weeks		60		15		3.0		11.0
	8 weeks		43		11		2.3		11.1
	9 weeks	41		19		2.1		9.0	
	10 weeks		34		9		2.0		8.9
	all season	38	31	19	15	2.2	1.9	9.1	8.7
LSD ($P = 0.05$)		9	10	5	8	0.4	0.3	1.5	1.7

^aFruit wt > 400 g, netting index > 2, without rotting and virus symptoms; ^byield in the first week of harvest; ^cmean of all fruits = $\Sigma_{i=1}^n$ netting value $\times$ fruit wt/Total yield; ^dtotal soluble solids

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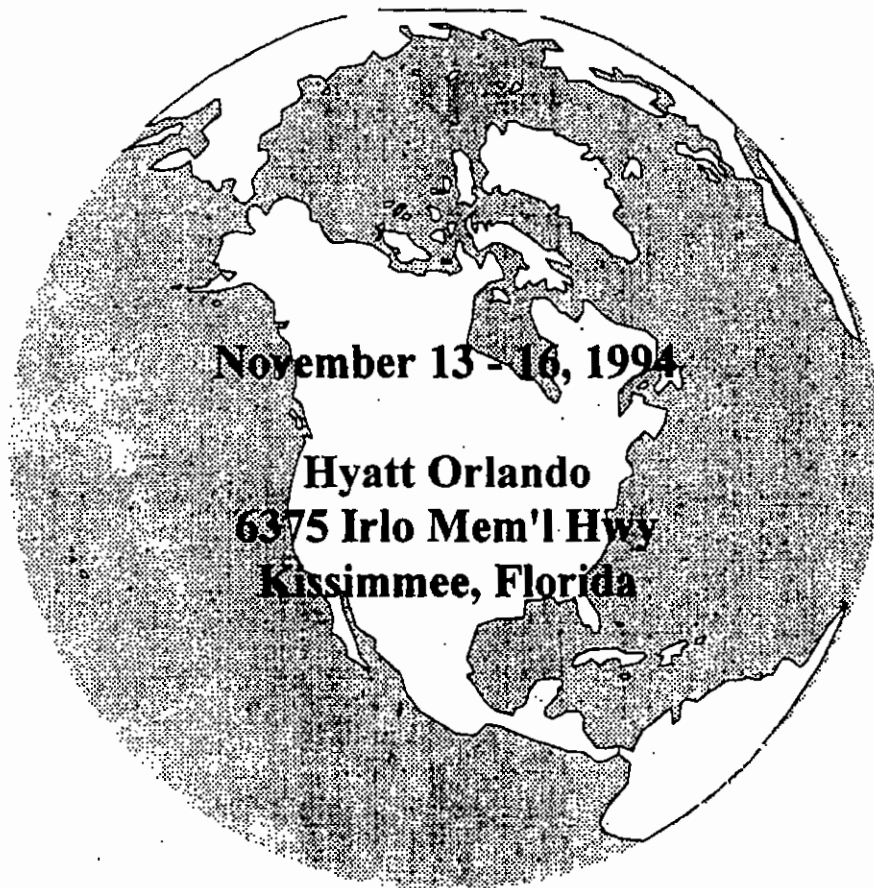
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Soil-borne Pest Control in Mulched Tomato
with Alternatives to Methyl Bromide

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Additional index words. fumigant, Lycopersicon esculentum,
nutsedge, Cyperus rotundus, nematode, Fusarium.

Abstract. Five soil fumigants, a contact nematocide and several combinations with pebulate herbicide were compared to methyl bromide/chloropicrin (98 and 2%, respectively) for control of nutsedge, Fusarium wilt and crown rot, and nematodes in tomato (Lycopersicon esculentum) in experiments conducted during the spring and fall of 1993. Chemical treatments did not affect tomato plant vigor during the spring, but plants were more vigorous in plots treated with methyl bromide than in those areas treated with SMDC (sodium methyldithiocarbamate), fosthiazate, or the combination of fosthiazate, SMDC and pebulate during the fall experiment. Dazomet and 1,3 dichloropropene + chloropicrin + pebulate were the only treatments which were as effective as methyl bromide for purple nutsedge (Cyperus rotundus) control. All fumigants reduced Fusarium wilt in both experiments. Fusarium crown rot was reduced by methyl bromide and 1,3 dichloropropene + chloropicrin in the spring, but in the fall all chemical treatments, except those containing SMDC, provided better crown rot control than methyl bromide. The number of tomato plants with root knot nematode galls on the crown roots and the severity of infestation was reduced by methyl bromide and 1,3 dichloropropene

chloropicrin.

Production of marketable fruit was not affected by alternative fumigant treatments compared to methyl bromide during the spring of 1993; however, in the fall, plots treated with fosthiazate alone produced fewer tomatoes than did those which recieved dazomet, SMDC, or 1,3 dichloropropene + chloropicrin + pebulate. Methyl bromide produced greater weight of fruit than chloropicrin, SMDC, or fosthiazate.

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FUMIGANT/HERBICIDE COMBINATIONS FOR
POLYETHYLENE MULCHED TOMATO

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Results of fumigant research in Florida indicate that Telone C-17 provides the most consistent nematode and soil-borne disease control in tomato of the methyl bromide alternatives tested to date; however, it, like all of the alternatives, provides little to no control of yellow and purple nutsedge. Nutsedge is a serious weed pest in many fields in Florida and will continue to increase in importance as crop rotation cycles shorten. Urbanization and water use issues are limiting the amount of new land available for crop production, thus growers are farming land longer and soil-borne pests are becoming more important. Heavy infestations of purple nutsedge have greatly reduced tomato yields in fumigant field trials demonstrating the importance of nutsedge control with any fumigant. Although Vapam and Basamid provide weed control in some areas of the world, they have not provided control of nutsedge equal to that obtained with methyl bromide in Florida. Telone C-17 seems to stimulate tuber sprouting at times and provides very little nutsedge control even under the best of conditions. No nutsedge control has been observed with chloropicrin.

Research was conducted during 1994 and 1995 to identify herbicides which could be applied to the soil under polyethylene mulch in combination with alternative fumigants to control nutsedge in tomato production in Florida. Emphasis has been placed on evaluating herbicides which are already registered for use on tomato in consideration of the brief time available before 2001 and the lengthy time normally involved in registration of new products.

Three experiments were conducted (spring 1994, fall 1994, and spring 1995) comparing purple nutsedge control with various herbicides in combination with Telone C-17. Pebulate was applied at 2 and 4 lb.a.i./acre in the first two experiments and 4 lb. in the third experiment. Trifluralin was applied at 1 and 2 lb.a.i./acre in the first experiment and was not included in subsequent tests due to poor performance. Napropamide was applied at 2 lb.a.i./acre in all tests. Lactofen was applied at 1 lb.a.i./acre in the

first two experiments and at 2 lb.a.i./acre in the last two trials. Metolachlor was included in the last test at 1 and 2 lb.a.i./acre. All herbicides were incorporated into the top 2 to 4 inches of the raised beds immediately after application with a tractor-powered rototiller. Telone C-17 was applied 8 inches deep in the soil through three chisels per bed following herbicide incorporation and beds were covered with polyethylene mulch within 1 minute of fumigant application.

Trifluralin provided no control of purple nutsedge. Lactofen performed erratically with good nutsedge control one season and none the next. Metolachlor provided good nutsedge control, especially at the 2 lb.a.i./acre rate; however, it was injurious to tomato plants. Pebulate consistently controlled nutsedge when combined with Telone C-17, although the level of control was not always as great as one would expect with methyl bromide.

An experiment was conducted in the spring of 1995 to determine if pebulate would control nutsedge as well as methyl bromide when combined with each of the alternative fumigants and to determine crop response to the combinations. Pebulate (4 lb.a.i./acre) was incorporated into the bed for all fumigants, except methyl bromide. Fumigants (methyl bromide (67/33), Telone C-17, Vapam, Basamid, and chloropicrin) were applied, and beds were covered with polyethylene mulch immediately after fumigant application.

Control of purple nutsedge with pebulate/fumigant combinations was as good as that obtained with methyl bromide. Tomato plant vigor was not affected by treatment when evaluated 2 weeks after transplanting. Combinations of pebulate with chloropicrin, Basamid or Telone C-17 produced fresh market tomato yields equivalent to methyl bromide. The combination of Vapam and pebulate produced more marketable fruit.

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EFFECT OF METAM SODIUM AND METHYL BROMIDE ON ROOT-KNOT NUTSEDGE AND DAMPOFF ON CUCUMBER CV. DASHER II

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In south Florida the cucumber farmer's most serious production problems are root-knot nematodes, soil-borne fungi and yellow nutsedge of the alternative fumigants do not adequately or consistently control all of these pests. However, metam sodium and chloropicrin are the only fumigants labeled for use on tomato and would provide cucumber growers in south Florida (Dade County, Homestead) with an alternative to methyl bromide. Chloropicrin alone will not provide adequate control of weeds or nematodes except at high rates which would be neither economical nor environmentally friendly. Metam sodium when applied at the 60 gallon per treated acre provides adequate control of soil-borne pest and reduces weed populations. Continued studies on vegetable crops from 1980 to 1999 in regards to the delivery systems for metam sodium has shown that soil injections and drenches followed by rapidly rototilling and plastic mulch film application are consistently more effective for the control of soil-borne pests and weeds than injection through drip irrigation tube(s). The purpose of this field study was to evaluate consistency of metam sodium application and compare it with the standard methyl bromide soil fumigation.

The commercial field trial was conducted on Krome gravelly loam in the spring of 1999. Prior to fumigation, soil beds were formed 38 inches wide and 6 inches high on 72 inch centers. Fertilizer at 30% of recommended N, K fertilizer and 100% of P fertilizer was banded and rototilled into the bed. Each treatment plot of methyl bromide and metam sodium was 10 acres. Within the 10 acre plots, subplots, 4 beds wide and 100 ft long, of control and fumigant, were selected at random and replicated 4 times.

Two soil fumigants, metam sodium and methyl bromide plus chloropicrin (MC33) were applied. Methyl bromide plus chloropicrin was injected at 250 lbs/acre. The fumigant methyl bromide plus chloropicrin was injected through 3 chisels, spaced at 9 to 10 in. apart. The metam sodium was injected at the irrigation pump at 6 gpm for a 40min duration and allowing 45 min to clear the metam sodium from the lines. The metam sodium beds were covered with 1.5 mil polyethylene film and the single bi-wall drip tube was in place 12 hrs prior to the fumigant injection. After 28 days the plastic was perforated in both the methyl bromide (MC33) and the metam sodium blocks to allow venting and 7 days later cucumber cv. Dasher II were direct seeded at a spacing of 12 inches in the row and 72 inches between the row. Supplemental fertilizer applications of 70% of recommended N, K was fertigated through the drip irrigation tubing.

Weed counts were determined at the termination of the field trial. The cucumber roots were evaluated for root-knot nematode galls on a rating of 1 to 9 with 1=0 galls to 9=80 to 100% galling at 4-weeks. Yields of marketable, extra large, large and medium cucumber fruit were evaluated.

Early picking packout of 'Dasher II' from the methyl bromide 10 acre plot, packed out 33, bu/acre Fancy fruits. The early packout of marketable (U.S. Fancy, No. 1, and No.2)

fruits from the methyl bromide plots packed out 98 bu/acre. The metam sodium 10-acre plot packed out 40 bu/acre fancy fruits. The early harvest of the of marketable cucumber fruits from the metam sodium plots packed out 95 bu/acre. The total yield after 9 harvest from the plots of methyl bromide yielded 125 bu/acre of Fancy, and 415 bu/acre of marketable fruit cartons as compared to the control with 12 bu/acre of Fancy, 21 bu/acre of marketable fruit. The metam sodium total harvest after 9 harvest yielded 119 bu/acre of Fancy, and 422 bu/acre of marketable fruits as compared to the control with 9 bu/acre Fancy, and 18 bu/acre of marketable fruits.

The mean weed counts in the methyl bromide plots was 12 yellow nutsedge per 100 ft of row. The mean weed counts in the metam sodium plots was 20 yellow nutsedge per 100 ft of row as compared to the untreated control with 2052 yellow nutsedge plants per 100 ft of row.

The percent root-knot galls after 4-weeks in the methyl bromide plots were 0.3 compared to the metam sodium plots provided root-knot gall percent of 0.9. The mean percent root-knot galls in the control was 98 percent.

The percent damp-off from the methyl bromide plots was significant at 0.1 and 0.8 from the metam sodium compared to the untreated controls at 72 percent dampoff.

In conclusion, the metam sodium application of 60 gal. per treated acre through a single drip irrigation tubing increased yields over the control. The standard methyl bromide (MC33) increased yields over the control. The weed control from the metam sodium and the methyl bromide treatments were significantly reduced weed development at the end of the harvest season. Metam sodium is still the only fumigant that can provide cucumber growers with some degree of controlling the soil-borne problems that was easily taken care of by the application of methyl bromide (MC33).

EFFICACY OF TELONE PRODUCTS IN FLORIDA CROPS: A SEVEN YEAR SUMMARY

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Thirty-five tomato trials, five pepper trials, and eight strawberry trials, conducted from 1993 to 1999, were summarized for this report. Trials were conducted primarily by University of Florida researchers and encompass the key production areas of Florida. Telone C-17 (78.3% 1, 3-dichloropropene + 16.5% chloropicrin) or Telone C-35 (61.8% 1, 3-dichloropropene + 35% chloropicrin) (Telone products) were applied in the bed at 35 gallons per treated acre and compared to the untreated check and to methyl bromide/chloropicrin (MB/Pic), primarily 67/33 (67% methyl bromide/33% chloropicrin) or 98/2 (98% methyl bromide/2% chloropicrin) mixtures. MB/Pic rates were usually 350 lbs/treated acre for the 67/33 formulation and 400 lbs/treated acre for the 98/2 formulation. Observations on crop yield, crop vigor, and soil-borne pest control for Telone C-17 or Telone C-35 in each trial were characterized as statistically superior to, equal to, or inferior to the untreated check and to MB/Pic standards. The frequencies of these characterizations were then tabulated. These trials were conducted over a number of years and raw data were not available for all trials. For these reasons, statistical analyses on which these characterizations were based were different for different trials. Mean separation analyses conducted by the researcher were used when raw data were unavailable, usually at the 0.05 level of probability. When raw data were available, analyses were either LSD or Tukey's HSD at the 0.10 level of probability. When more than one treatment of the same product at rates of interest were included (i.e. two formulations of MB/Pic), observations were characterized as statistically equal unless all observations for multiple treatments were statistically superior or inferior to the comparative treatment.

Nematode Control: Control of root-knot nematodes (*Meloidogyne* spp.) with either MB/Pic or Telone products was equal to or superior to the untreated check in 100% of observations in tomatoes, peppers and strawberries. Telone products were equal to or superior to MB/Pic for control of root-knot nematodes in nearly 95% of observations on tomatoes and in 100% of observations on peppers and strawberries. Control of sting nematodes (*Belonolaimus* spp.) with Telone products or MB/Pic was equal to or superior to the untreated check in all observations on all crops. Telone products were equal to MB/Pic for control of sting nematodes in 100% of observations on all crops. Telone products were equal to or superior to the untreated check for control of stubby root nematodes (*Trichodorus* spp.) in just under 80% of observations on tomatoes and peppers, while MB/Pic was equal to the untreated check in 100% of observations. Telone products were inferior to MB/Pic in just under 40% of observations for control of stubby root nematodes. When all nematode species on all crops were considered, Telone products were equal to or superior to MB/Pic in over 90% of observations.

Disease Control: Very little information on soil-borne diseases was available from pepper or strawberry trials, so summary information presented here is limited to tomatoes. Control of Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*) with Telone products was equal to that with MB/Pic and both products were superior to the untreated check in 70% of observations. Telone products and MB/Pic were superior to the untreated check for control of Fusarium crown and root rot (*Fusarium oxysporum* f. sp. *radicis-lycopersici*) in 70 and 55% of observations, respectively. Both products were also inferior to the untreated check in 15% of observations. Compared to MB/Pic, Telone products provided statistically superior control of this disease in about 7.6% of observations and was equivalent to MB/Pic in the remaining observations. For control of southern blight (*Sclerotium rolfsii*), both Telone products and MB/Pic were equal to or superior to the untreated check in all observations. Telone products were statistically superior to MB/Pic for control of southern blight in a little over 10% of observations and were equal to MB/Pic in the remaining observations.

Weed Control: In these trials, Telone products were usually combined with the herbicides Tillam (pebulate) on tomatoes or Devrinol (napropamide) on peppers or strawberries. Thus, comparisons are between MB/Pic and Telone products + a herbicide. The key weed pests of Florida vegetables are nutsedges (*Cyperus esculentus* and *C. rotundus*). Both Telone products + a herbicide and MB/Pic resulted in nutsedge control that was equal to or superior to the untreated check in 100% of observations. Telone products + a herbicide resulted in nutsedge control that was equal to MB/Pic in about 90% of observations across all crops. Grasses and broadleaf weeds were not usually evaluated in these trials. When they were, Telone products + a herbicide provided control that was equivalent to MB/Pic in 100% of observations.

Crop Vigor: Both MB/Pic and Telone products resulted in tomato vigor that was statistically equal to or superior to the untreated check in 100% of observations and superior to the untreated check in about 60% of observations. Telone products resulted in tomato vigor ratings that were statistically equal to MB/Pic in over 95% of the observations. In peppers, Telone products and MB/Pic were statistically superior to the untreated check in over 70% and 55% of observations, respectively. Telone products were equivalent to MB/Pic in 100% of observations. Vigor of strawberries was statistically superior to the untreated in about 28% of the observations with MB/Pic and about 25% of observations with Telone products. Telone products resulted in statistically higher vigor of strawberries than did MB/Pic in about 8% of observations and in statistically equivalent vigor in the remaining observations.

Crop Yield: Yields of tomatoes treated with Telone C-17 were 95% of those with MB/Pic and yields with Telone C-35 were over 103% of those with MB/Pic. In peppers, yields with Telone products were 100% of those with MB/Pic. Strawberry yields with Telone products were about 98% of those with MB/Pic.

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NUTSEDGE (*Cyperus* spp.) MANAGEMENT IN CUCURBITS.

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Purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*Cyperus esculentus* L.) were the most troublesome weeds of vegetables in a survey of Georgia county extension agents (Webster and MacDonald unpublished data). A plasticulture system can prevent weed growth, however nutsedges pierce the polyethylene barrier. Harrison and Fery (1998) were concerned that nutsedges will become unmanageable in vegetables after elimination of methyl bromide. Nutsedges rely on vegetative reproduction (i.e. tuber formation) (Thullen and Keeley 1979). Purple nutsedge tubers had a half-life of 16 months and longevity of (99% mortality) 42 months (Neaser et al. 1997). Effective nutsedge management programs must address tuber production and viability. I will briefly review current research on nutsedges, including an evaluation of: 1) the spatial dynamics of nutsedge populations over a growing season, 2) the effect of a combination of temperature and duration of exposure on nutsedge tuber viability, and 3) tolerance of squash and cucumber to halosulfuron, a herbicide with excellent nutsedge efficacy.

While similar in appearance, yellow and purple nutsedge differ greatly in growth habit. Single pre-sprouted yellow and purple nutsedge tubers were planted in a nutsedge-free area and growth monitored at three and six months. After six months of growth, yellow nutsedge averaged 140 shoots/plot and shoots expanded a maximum of 20 cm from the parent tuber. In contrast, purple nutsedge shoots expanded a maximum of 300 cm from the parent tuber and produced an average of 280 shoots/plot. While a greater number of shoots were produced by purple nutsedge, these shoots were spread over a larger area than were yellow nutsedge. Contour maps indicated that maximum purple nutsedge shoot densities were around 200 to 300 shoots/m², while yellow nutsedge densities often exceeded 7000 shoots/m² (most of the yellow nutsedge shoots were within a 12.7 cm by 12.7 cm quadrat). Each nutsedge shoot was associated with at least one tuber (Willis and Briscoe 1970; personal observation). This study indicates that purple nutsedge tubers can be distributed a significant distance from the parent tuber after just six months of growth, while yellow nutsedge does not spread as far from the parent tuber.

Utilizing elevated temperatures (e.g. solarization, steam, electromagnetic radiation) to eliminate or weaken nutsedge tubers may be a future component of a weed management system that replaces methyl bromide. Purple nutsedge tuber viability decreased in an inverse linear manner over an increasing range of temperatures (30 to 90 C) when exposed for 30 minutes (Rubin and Benjamin 1984). In preliminary studies, yellow nutsedge tubers were more sensitive to high temperatures than were purple nutsedge. Reanalysis of the data from Egley (1990) revealed that median lethal temperatures (temperature required to kill 50% of the population) for eight common weeds seeds at 12 hours of exposure were 50 to 66 C. In comparison, our studies indicated that pre-sprouted yellow nutsedge tubers exposed to 50 C for as few as 30 minutes, resulted in greater than 80% tuber mortality. However, yellow nutsedge tubers exposed to 45 C for

8 hours resulted in less than 5% tuber mortality. In a plasticulture system in southern Louisiana greater than 60% of the days exceeded each of the following: 50 C at a depth of 10 cm, 55 C at 5 cm, and 60 C at the soil surface (Arora and Yaduraju 1998). Knowledge of the relation among tuber mortality, temperature, and duration of exposure may allow for the development of systems that influence tuber viability.

Halosulfuron effectively controls nutsedges and has potential for use in many vegetable crops. Halosulfuron reduced purple nutsedge tuber populations 35 to 50 % when applied in consecutive years (Webster and Coble 1997). Halosulfuron controls the tuber attached to sprayed foliage (Molin et al. 1997), whereas many other herbicides will only kill the foliage and permit the tuber to regrow. A greenhouse study was conducted to determine the relative susceptibility of direct seeded and transplant cucurbits (six squash and six cucumber cultivars) to preemergence and postemergence applications of halosulfuron. An inverse relation between crop biomass and increasing rates of halosulfuron existed for both direct-seeded and transplanted cucurbits. Transplanted squash had the greatest injury averaged over all rates of halosulfuron, with a plant biomass 60% of the nontreated control. Transplanted cucumbers were the most tolerant of halosulfuron with a plant biomass 94% of the nontreated control. Visual crop injury rating indicated that cucumber was more tolerant to halosulfuron than squash. Visual rating of cucumber injury increased with halosulfuron rate for direct seeded plants (up to 22% injury), while injury on transplants were independent of halosulfuron rate. Injury to direct-seeded squash treatments that included a preemergence application increased with halosulfuron rate with maximum injury $\geq 33\%$ at 53 g ai/ha halosulfuron. Postemergence applications to direct-seeded squash and all applications to transplanted squash had more subtle crop injury ranging from 12 to 19%. This demonstrates that while there is some variability in halosulfuron tolerance among the tested cucurbit cultivars, halosulfuron may be a viable alternative to methyl bromide for control of nutsedges in a plasticulture system.

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NUTSEDGE, ROOT-KNOT NEMATODE, AND FUNGAL CONTROL WITH FUMIGANT ALTERNATIVES TO METHYL BROMIDE IN POLYETHYLENE MULCHED TOMATO

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Tomato (*Lycopersicon esculentum* Mill.) is the most valuable vegetable grown in Florida. During the 1992-93 season, the crop was grown on 19,600 ha with an on farm value of \$626 million. The crop is grown very intensely with the use of broad-spectrum fumigants, polyethylene mulch, adequate rates of fertilizer, irrigation, and with the use of pesticides to control foliar insects and diseases. Soil pests that commonly inhabit typical tomato production sites include nematodes, fungi, bacteria, insects, and weeds. The fumigants of choice, because of their high level of effectiveness at an economical cost, are methyl bromide and methyl bromide-chloropicrin combinations. It is apparent that no other available chemical provides this spectrum of control of pests. Studies were conducted with polyethylene mulched tomatoes to evaluate possible preplant fumigants or combinations of chemicals as alternatives to methyl bromide as one of five similar studies in Florida.

Tomatoes were grown on an Arrendondo fine sand in Gainesville, FL during the spring of 1994 on a site known to be heavily infested with purple and yellow nutsedge (*Cyperus rotundus* L. and *Cyperus esculentus* L.) and moderately infested with root-knot nematode *Meloidogyne incognita* (Kofoid & White) Chitwood. The two nutsedge species are very serious weed pests and can easily grow through polyethylene mulch if not controlled. After soil preparation, beds 1.8 m apart were made and part of the fertilizer was applied in the 0.9m bed along with soil applied fumigant and herbicide treatments. Drip tubing for water, fertilizer, and fumigant application and polyethylene mulch were then applied.

Soil injected treatments were chloropicrin (390 kg·ha⁻¹), chloropicrin + pebulate (390 + 4.5 kg·ha⁻¹), (pebulate was applied on the bed and incorporated 15 to 20 cm before fumigants were injected with three chisels per bed), 1,3-dichloropropene + 17% chloropicrin (327 liter·ha⁻¹), 1,3-D+C17 and pebulate (327 liter·ha⁻¹ + 4.5 kg·ha⁻¹), methyl bromide-chloropicrin (450 kg·ha⁻¹ 98-2%), and methyl bromide-chloropicrin (392 kg·ha⁻¹ 67-33%). Dazomet (448 kg·ha⁻¹) and metham sodium (935 liter·ha⁻¹) were applied on the bed surfaces and incorporated. Dazomet was also watered into the soil with 6 mm depth of water before mulch application. Metham sodium (935 liter·ha⁻¹) and enzone (1870 liter·ha⁻¹) were applied through the drip irrigation system through two drip tubes per bed. Three weeks after fumigant application, tomato was transplanted into the treated soil. Additional applications of enzone (2 applications of 18.7 liter·ha⁻¹) were made through the drip irrigation system during the crop growth period.

In this study, nutsedge and root-knot nematode were major pests. Tomato fruit yields were closely related to the degree of nutsedge and root-knot control provided by the various treatments. Counts of emerged nutsedge seedlings were made approximately 5 and 10 weeks after transplanting tomato. On both dates, nutsedge population densities were high and were higher on the drip tubing side of the bed than on the opposite and drier side of the bed. Nutsedge counts on the tubing side of the bed at the two evaluations were 24 and 30 plants 0.095 m^2 , respectively, with no treatment. Nutsedge counts at the earliest evaluation were low per 0.095 m^2 (number in parenthesis) with methyl bromide 98-2 (2), methyl bromide 67-33 (3), chloropicrin + pebulate (4), and with 1,3-D + C17 + pebulate (5). Counts were slightly higher with chloropicrin (9) and 1,3-D + C17 (12) alone. Nutsedge control was poor with the other treatments and emerged numbers were similar to those obtained with no treatment. At the second evaluation, counts averaged 8/ 0.095 m^2 with the two methyl bromide treatments and 13/ 0.095 m^2 with the two pebulate containing treatments and 28/ 0.095 m^2 with the other treatments.

Root-knot galling indices were lower ($P=0.05$) on tomato roots in plots treated with methyl bromide and 1,3-D + C17 than in plots treated with chloropicrin, metham sodium (drip), dazomet + water and the untreated control. Marketable fruit yield was negatively correlated ($P=0.01$) with the root knot galling index.

Fruit were harvested at the breaker stage and were graded into marketable size categories of extra-large, large, and medium fruits. Relative fruit yields were 100% with the two methyl-bromide treatments, 86% with the two pebulate containing treatments, 60 to 70% with chloropicrin, 1,3 D + C17, dazomet, and metham sodium drip applied, 45% with soil applied metham sodium, 47% with enzone, and 40% with no treatment.

Three predominate pathogenic fungi, *Rhizoctonia solani* Kuhn, *Macrophomina phaseolina* Tassi (Goidanich), and *Fusarium* spp., were recovered from tomato roots assessed in mid-May, and mid-June. Negative correlations between marketable fruit yield and fungal counts were significant ($P=0.01$) for *R. solani* at the mid-June sampling and for the combined total of fungi recovered at the mid-May ($P=0.05$) and mid-June ($P=0.01$) sampling. At the first sampling, all treatments except dazomet + water significantly reduced the combined total of fungi. However, at the later sampling, total fungal counts were reduced significantly only with chloropicrin or methyl bromide containing treatments.

These studies indicate that no one pesticide can provide the broad-spectrum control provided by methyl bromide. Where nutsedge is present, pebulate provided partial control of this weed and apparently allowed sufficient plant growth to obtain a 86% relative yield. This is probably not adequate for long term tomato production. These data indicate that with further work, a more effective treatment may be found.

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ECONOMIC IMPACTS OF SWITCHING FROM PRE- PLANT FUMIGATION WITH METHYL BROMIDE

Lori Lynch and Janet Carpenter

Since phase out schedules for methyl bromide were announced under the Montreal Protocol and the Clean Air Act, researchers have been investigating alternatives to methyl bromide fumigation for both pre-plant and post-harvest uses. They have also been exploring methods of decreasing emissions of methyl bromide through closed chambers and impermeable tarps. As the year 2001 approaches, growers are exploring these alternatives as options after the ban on methyl bromide production and importation comes into place. We examine the most likely alternatives that growers will use and how these methods will alter yields and costs. Given the next best alternatives, we examine impacts on crop production, prices and society's welfare.

Methyl bromide is primarily used as an agricultural fumigant in the high-valued horticultural crops in California and Florida as well as Georgia, South Carolina, and North Carolina to a lesser degree. In the markets for these crops, the primary competitors are the Mexican states of Baja California, Sinaloa, and Sonora. These states will be able to replace some of the production losses incurred in the United States after growers stop using methyl bromide. California uses 15.325 million lbs. for pre-plant fumigation ranging from high valued use on strawberries to spot treatments in orchards. Florida uses 13.35 million lbs. with the highest valued uses in double cropping systems. Georgia uses 1.541 million lbs. in tomatoes, tobacco beds, and onions. South Carolina uses 1.453 million lbs. in tomatoes. Similarly, North Carolina uses 1.819 million lbs. in tomatoes, peppers, strawberries and tobacco beds.

We examined research documents, sought expert opinion, and conducted two workshops to elicit information and feedback on the possible alternatives that growers could employ. These alternatives included: 1,3-Dichloropropene (1,3-D), Chloropicrin, Metam Sodium, Dazomet, Methyl Iodide, Enzone, Ethoprop, Aldicarb, Carbofuran, Oxamyl, Fenamiphos, Benomyl, Metalaxyl, Biological Control, Botanical Extracts, Cover crops, Crop Rotation, Fallow, Flooding, Greenhouse Production, Hot Water treatment, Hot Water Dips, Plastic Barriers, Resistance and Grafting, Solarization, Steam, Soil Amendments, Organic Production, and other chemical and nonchemical combinations. After this data collection, we determined that the highest profit alternative in Florida vegetable production will be 1,3-D/Chloropicrin with Pebulate as an herbicide for nutsedge. Growers with drip irrigation systems who decide to double crop will use Metam Sodium before planting the second crop. Florida turf will shift to limited fumigation with 1,3-D or use a mix of other inputs to compensate for absence of

methyl bromide. Cut flowers grown in the field are also assumed to shift to 1,3-D in both California and Florida. California tomatoes, peppers, strawberries, tree and vine crops, and nurseries will shift to 1,3-D/Chloropicrin. Strawberry growers are assumed to use more Chloropicrin than other crops for control of soil borne pathogens. Greenhouse crops such as roses and carnations will shift to steam sterilization.

Our assumptions are based on the best available information at this time. We are aware however that there are regulatory problems with some growers shifting to these alternatives. For example, California regulations only permit the use of 1,3-Dichloropropene under restrictive conditions. 1,3-Dichloropropene can not be applied in a buffer zone of 300 feet around any school, hospital, business or residence. The maximum amount of 1,3-Dichloropropene that can be applied without tarpaulin is 35 gallons per acre. The maximum amount under a tarpaulin is 24 gallons per acre. Within a 36 square mile area, no more than 5,000 gallons can be used if any application is made at depths less than 18 inches. If all applications are made at depths of 18 inches or more, 9,000 gallons can be applied in the area. These quantities are not sufficient for the conversion of all the acres that would desire to change. In addition, recent actions by certain Agricultural Commissioners indicate that Chloropicrin rates may be limited in the future to avoid potential conflict with residents in areas in proximity to fumigated fields. Recent research using multiple year trials suggests that the strawberry yield losses using 1,3-D and Chloropicrin will be higher than those reported previously (over 15% rather than 3-8%). In addition, the lack of methyl bromide in the nursery stage results in less vigorous and lower yielding plants than under a methyl bromide regime. Concern remains that without methyl bromide tree and vine nurseries will not be able to guarantee nematode-free products as required by law. The use of Pebulate, the preferred herbicide for southeastern grown tomatoes, is not allowed on hand transplanted tomatoes, which is the current practice. Even with the fast track for methyl bromide alternatives, it is not clear that Pebulate will be available for use in the tomato industry by the year 2001. 1,3-D bed fumigation in Florida would require worker safety equipment that will be very uncomfortable due to heat. Fortunately fumigation for the majority of Florida's crops happens during cooler seasons. In addition, growers could shift to full-field fumigation where the number of workers in the field at the time of application could be minimized.

Using these assumptions, we computed the increase in revenue generated from using one pound of methyl bromide rather than the next best alternative assuming market prices do not change for the crop. For example, California South Coast strawberries gain an extra \$41.43 from the availability of a pound of methyl bromide rather than using 1,3-D/Chloropicrin. If they use an average of 115 lbs. of methyl bromide per acre as indicated in the California Pesticide Use database, this is equivalent to a loss of \$4764 an acre. Estimates for other crops are included in the Table 1.

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Table 1. Increased revenue: Methyl bromide compared to best alternative

Region and Crop	Methyl bromide use (lbs)	Value (\$/lb)
CA S. Coast Strawberry	1,394,720	\$41.43
CA Carnations	12,000	\$36.25
Cent. FL Strawberry	914,610	\$33.48
CA C. Coast Strawberry	2,462,202	\$28.24
CA Perennial Nursery	170,302	\$20.30
SW FL Tomato-Cucumber	335,160	\$18.67
Cent. FL Pepper-Watermelon	849,268	\$13.93
CA Rose Nursery	290,474	\$12.40
SW FL Tomato-Watermelon	1,934,324	\$11.67
Cent. FL Eggplant	50,568	\$11.37
SW FL Eggplant	50,568	\$11.37
SE FL Eggplant	303,800	\$11.27
CA S. Coast Tomato	198,512	\$11.23
Dade Eggplant	39,200	\$10.99
CA Strawberry Nursery	239,772	\$10.20
SW FL Tomato-Squash	619,360	\$10.09
CA S. Desert Tomato	76,304	\$9.43
SE FL Pepper	1,409,632	\$9.10
SW FL Pepper	1,695,400	\$8.29
SW FL Watermelon	46,648	\$7.17
NC Strawberry	155,040	\$6.72
Cent. FL Watermelon	46,648	\$6.64
FL Cut Flowers	718,530	\$6.44
W. FL Watermelon	110,740	\$6.14
CA Field Flowers	640,787	\$5.40
CA Sac. Walnut	126,678	\$5.00
CA SJ Walnut	98,604	\$5.00
CA Sac. Almonds	81,840	\$4.99
CA SJ Almonds	773,956	\$4.99
CA N. Coast Wine Grapes	814,042	\$4.96
CA C. Coast Wine Grapes	273,294	\$4.96
CA Sac. Peach and Nectarine	266,034	\$4.90
CA Sac. Plum and Prune	125,953	\$4.90
CA SJ Peach and Nectarine	181,818	\$4.90
SW FL Tomato	939,624	\$4.69
SE FL Tomato	1,110,732	\$4.64
W. FL Tomato	408,660	\$4.54
Cent. FL Tomato	3,263,008	\$4.27
Dade Tomato	868,868	\$4.25
SC Tomato	590,548	\$4.15
CA S. Coast Pepper	194,194	\$4.08
CA S. Desert Pepper	329,602	\$3.85
CA Roses	116,000	\$2.05
FL Turf	3,049,515	\$1.78
FL Caladium	392,236	\$1.38
NC Tomato	244,200	\$1.04
GA Tomato	689,500	\$0.97
NC Peppers	204,000	\$0.94
CA SJ Table Grapes	489,600	\$0.50
CA SJ Wine Grapes	69,344	\$0.50

A Meta-analysis of Strawberry Yield Response to Preplant Soil Fumigation with Combinations of Methyl Bromide-chloropicrin and Four Alternative Systems

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Additional index words. chloropicrin, dichloropropene, *Fragaria xananassa*, metam sodium, methyl bromide

Abstract. Yield for annual California strawberry (*Fragaria xananassa* Duch.) production systems in soils treated with combinations of methyl bromide-chloropicrin (MB:CP) were compared with four alternative soil treatment systems using meta-analysis. Studies represent 11 production seasons, and were conducted at three distinct locations in California. Fumigation with mixtures of methyl bromide (MB) and chloropicrin (CP) increased yield significantly compared with any and all alternatives lacking MB. In a combined analysis of 45 studies, fumigation with MB:CP compounds increased yield an average of 94.4% ($d_s = 2.874 \pm 0.098$) compared with yields for plants in nonfumigated (NF) soils. Further, the effect of MB:CP fumigation increased over the first three strawberry cultivation cycles: MB:CP-fumigated soils provided a 59.2% ($d_s = 2.166 \pm 0.146$) yield advantage when one cycle of fumigation was omitted, a 100.2% ($d_s = 3.000 \pm 0.143$) advantage when two cycles were omitted, and a 148.4% ($d_s = 6.201 \pm 0.348$) yield advantage when three or more cycles of MB:CP were omitted. In a combined analysis that included 34 studies, soil fumigation with MB:CP conferred a 9.6% ($d_s = 0.751 \pm 0.087$) yield advantage over fumigation with CP alone. Soils treated with MB:CP yielded 6.8% ($d_s = 0.437 \pm 0.114$) more fruit than those treated with very high rates of CP (336–396 kg·ha⁻¹), and 15.4% ($d_s = 1.190 \pm 0.134$) more than soils treated with commercially realistic rates (168–224 kg·ha⁻¹). Similar to the comparison using NF soils, the efficacy of very high rates of CP appeared to diminish over cycles of strawberry cultivation; MB:CP increased yield 2.2% ($d_s = 0.043 \pm 0.162$) in the first CP production cycle, 10.6% ($d_s = 0.588 \pm 0.174$) and 13.7% ($d_s = 2.054 \pm 0.401$) in the following two cycles. Combinations of dichloropropene (DP) and CP were no more effective than were lower rates of CP alone, and MB:CP conferred a 14.4% ($d_s = 0.962 \pm 0.162$) yield advantage over mixtures of DP:CP. Mixtures of MB:CP increased yield 29.8% ($d_s = 3.199 \pm 0.287$) compared with metam sodium (MS). The standardized effect was similar when comparing MB:CP combinations with either MS or NF soils, suggesting little effect of MS on the yield response. Chemical names used: trichloronitromethane (chloropicrin); 1,3-dichloropropene (dichloropropene); sodium N-methyldithiocarbamate (metam sodium).

Preplant soil fumigation was originally investigated as a means for controlling *Verticillium dahliae* Koch (Wilhelm and Koch, 1956) in strawberry. Subsequent studies demonstrated advantages of preplant soil fumigation for at least three horticultural issues: weed control, control of lethal pathogens and nematodes, and a general growth and yield response that appears independent of specific host-pathogen interactions (Wilhelm et al., 1961, 1974). Studies of a range of other fumigation alternatives generally concluded that a synergistic effect of compounds containing methyl

bromide (MB) and chloropicrin (CP) made mixtures of these fumigants the most effective (Wilhelm and Paulus, 1980).

As a consequence of fumigation research conducted during the past half-century, preplant soil fumigation with mixtures of 2 MB:1 CP (by weight) at ≈ 390 kg·ha⁻¹ was standard for the California strawberry industry by the mid-1970s, and continues to be at present (Larson and Shaw, 1995a). However, concerns about the role of the halogen compound MB in ozone depletion emerged in 1990, and international regulatory restrictions may preclude future use of soil fumigants that include this chemical. Anticipating a future regulatory phaseout of MB, researchers in California have engaged in a decade-long effort to evaluate and quantify the benefits of soil fumigation, and determine the efficacy of other available chemical and nonchemical alternatives for current cultivars and production systems.

The objective of the research synthesis that follows was to compare strawberry productivity across a range of soil treatments, essen-

tially from minimal treatment such as repeated use of nonfumigated (NF) soils (with or without crop rotation) to application of alternative chemicals at high rates, in an effort to quantify the consequences of a ban on MB. This synthesis is limited in scope in that it does not consider the consequences of lethal pathogens that are likely to be a greater problem with some of the available alternatives. Further, this analysis does not quantify reductions in fruit quality, economic losses due to the cost of alternative chemicals or fruit quality reduction, or capital costs and/or yield reductions that might accrue as a result of any changes in cultural practice changes required by alternatives to MB:CP. This synthesis also considers only yield effects for soil treatments applied in the fruiting field. Strawberry production systems depend on preplant soil fumigation in a number of nursery propagation steps, and preliminary indications suggest that problems may arise for both plant productivity and quality using available alternatives (Larson and Shaw, 1995b). The effects of eliminating MB on nursery production, plant quality, and eventual yield reduction due to reduced nursery plant quality will be considered separately. This synthesis begins by defining strawberry performance in the NF control. Thereafter, the choice of comparison treatments was limited to those that had demonstrated some promise in prior experiments, and to chemical alternatives currently registered and thus available for use in California. As a consequence, several chemical and nonchemical alternatives that had either shown little effect in prior trials or are not currently registered in California were not included. Lastly, several of the chemical alternatives were tested at rates too high to be legally, economically, or socially feasible in operational production systems; these trials were included to provide boundaries for efficacy estimates.

Materials and Methods

The individual studies used for this research synthesis were conducted at three macro-locations within California: Irvine, at the south edge of the Los Angeles basin (33°40', 117°43'); Oxnard, ≈ 97 km north of Los Angeles (34°13', 119°11'); and Watsonville, ≈ 130 km south of San Francisco (36°56', 121°46'). These locations are representative of the environments that produce >97% of the strawberries grown in California, or $\approx 80\%$ of those produced in North America (Faxon, 1997). Results were obtained from trials conducted on three subsites in the Irvine region, two in the Oxnard region, and three in the Watsonville region.

The trials included in this synthesis extend from 1987 to 1997; most were conducted after 1992, as a consequence of increasing concerns about future availability of MB. Fumigation trials prior to 1987 frequently used germplasm no longer considered commercially viable, a potentially confounding factor eliminated in this synthesis.

Most of the trials were conducted using commercial cultivars adapted to the specific

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test region chosen, although a few comparisons included advanced selection materials from the Univ. of California (UC) strawberry improvement program, and two of the NF trials used cultivars of other North American origin. Likewise, several of the studies included runner plants from nurseries treated with different fumigants. Where multiple cultivars were used or where several nursery fumigation treatments were applied, the standard deviations used for weighting in combined analysis were calculated using pooled within-genotype or within-nursery-treatment sums of squares.

The results presented in this synthesis represent a reasonably complete array of those studies conducted to test fumigation alternatives by public sector researchers in California between 1987 and 1997. Original results requested from two authors for four studies were no longer available, and because the published results lacked the necessary parameters (means, sds, sample numbers) for inclusion in a meta-analysis, these were omitted. Also, results for six studies were judged proprietary by their originators and not made available for this synthesis. The vast majority of research results synthesized here were reported in symposia, industry bulletins, or are unpublished at present because of recent completion; these publications rarely included the necessary parameters for inclusion in a meta-analysis. In these cases, parameters were obtained from raw data provided by the original authors and reanalyzed for this synthesis. Typically, individual studies contained an industry standard control (fumigated with MB:CP), a NF control, and one or more chemical alternatives. Individual comparisons were made between the industry standard treatment (MB:CP) and each of several different alternatives within a single trial. Thus, results from the MB:CP treatment were used in multiple comparisons. As a consequence, comparisons of the different alternatives are not independent, but their covariance is expected to be large only when very small numbers of studies are evaluated, and thus will be of little importance here.

Study results were combined following the meta-analysis procedures of Hedges and Olkin (1985), as summarized in Olkin and Shaw (1995). Meta-analysis refers to a set of statistical techniques developed to provide a quantitative comparison of research results obtained from many independent studies. These techniques adjust for differences in error rate among studies and weight individual results based on both intrinsic error and sample size. In our synthesis, yield differences for treated and control groups in individual studies were converted to standardized effects, d , as:

$$d = \frac{\bar{X}_T - \bar{X}_C}{s} \quad [1]$$

$\bar{X}_T$ and $\bar{X}_C$ are means for the treated and control groups, respectively, and s is the pooled standard deviation for both groups. To obtain a composite estimate for the magnitude of a given treatment effect, the d_i 's from individual studies were weighted according to individual

study error rates, $\hat{\sigma}^2(d_i)$, where:

$$\sigma^2(d_i) = \frac{n_i^T + n_i^C}{n_i^T n_i^C} + \frac{d_i^2}{2(n_i^T + n_i^C)} \quad [2]$$

In Eq. 2, n_i^T and n_i^C are the numbers of replications for treated and control groups, respectively, and d_i is the estimated treatment effect for the i^{th} study, $i = 1, \dots, k$. The weight, w_i , assigned to each effect size estimate is inversely proportional to its variance and was computed as:

$$w_i = \frac{1/\hat{\sigma}^2(d_i)}{\sum [1/\hat{\sigma}^2(d_j)]} \quad [3]$$

and the combined estimate, d_+ , of effect size was calculated as:

$$d_+ = w_1 d_1 + w_2 d_2 + \dots + w_k d_k = \sum w_i d_i \quad [4]$$

Statistical comparisons were made using 95% confidence intervals constructed from the estimated variance of the combined effect size, $\hat{\sigma}^2(d_+)$, calculated as:

$$\hat{\sigma}^2(d_+) = \frac{1}{\sum [1/\hat{\sigma}^2(d_j)]} \quad [5]$$

A confidence interval for the combined effect size was determined as $d_+ \pm c_{\alpha/2} \hat{\sigma}(d_+)$, with $c_{\alpha/2}$ being the appropriate coefficient obtained from the normal distribution for the chosen confidence interval; for example, 1.96 for a 95% confidence interval.

Sufficient numbers of studies were obtained to compare four alternatives with the MB:CP industry standard: a NF control, CP alone at high and moderate rates, mixtures of dichloropropene (DP) and CP, and metam sodium (MS). In all cases, the critical comparison was between the current industry standard and an alternative, with MB:CP designated as the treated group and one of the alternatives listed above as the control. Thus, the standardized effect sizes provided by meta-analysis, statistical comparisons based on their confidence limits, and the unweighted percentage increase in yield provide a direct comparison between efficacy of fumigation using MB:CP and that of each of the designated alternatives. Figures are expressed in standardized effect size or percentage advantage for the current fumigation system, but could be expressed as relative losses for the alternatives by simple transformation.

Because most trials included both an industry standard and a NF control, comparison between fumigation with MB:CP mixtures and the absence of fumigation is the best tested of the treatment effects evaluated here; 45 studies were available for this comparison (Table 1, study set "N" in the far right column). Trials with NF included both those that followed strawberry cultivation directly with another strawberry crop and those that include a crop rotation other than strawberry. Prior work showed little difference in fumigation response with either 1 or 20 years rotation out of strawberry (Larson and Shaw, 1995a). Similarly, no mean difference was apparent among sets of studies established with and without

crop rotations consisting of alternate years of strawberry and a barley (*Hordeum vulgare* L.)/fava bean (*Vicia faba* L.) cover crop that was incorporated into the soil every other spring, thus any rotation effect was ignored. Trials differed in the number of strawberry production cycles since the last fumigation cycle, and we subdivided our NF studies into sets with one, two, or more than two strawberry cycles to evaluate the changes in relative productivity over time.

Direct comparison of yield for plants in soils fumigated with MB:CP mixtures and those grown in soils fumigated with CP alone were possible using 34 studies (Table 1, study set "C" in the far right column). Twenty-three of these studies were conducted using CP at rates of 336 kg-ha⁻¹ or greater; due to the cost of materials and the social consequences of emissions of this compound, such rates are not likely to be commercially realistic. Eleven studies were conducted using moderate, and more realistic, rates (121–224 kg-ha⁻¹). Rate differences were compared in a subdivided meta-analysis. The effect of high rates of CP on yield was also evaluated by subdividing the 23 high-rate studies over the number of cycles since the last fumigation with MB:CP combinations; a similar subdivision was not possible for CP at moderate rates due to an insufficient number of studies.

Ten studies were available for comparing yields of plants grown in soils treated with MB:CP vs. DP:CP mixtures (Table 1, study set "D" in the far right column). These 10 studies are a heterogeneous mix with substantial differences in the total quantity of product applied (336–666 kg-ha⁻¹) and, importantly, from 94–235 kg-ha⁻¹ of CP as part of the mixture. Several of the studies used DP at rates that exceed the maximum currently allowed by regulatory agencies.

Eight studies were included in yield comparisons for MB:CP vs. MS (Table 1, study set "M" in the far right column). Seven of the eight studies were conducted using the recommended rates of 275–305 L-ha⁻¹ a.i. of MS, the other used 153 L-ha⁻¹ a.i. The treatment differences were somewhat larger for this comparison, and comparisons were rather precise despite inclusion of relatively few studies. Fewer studies were available for evaluating the effect of MS on strawberry yield during the past 11 seasons, probably because a large number of prior studies had routinely demonstrated this to be a less effective soil treatment (Himelrick and Dozier, 1991). Three studies not included because they lacked appropriate statistical information will be discussed to support these comparisons.

Results

Yields were larger following fumigation with MB:CP than for NF treatments in all studies, and these differences were statistically significant or highly significant in 41 of the 45 individual studies evaluated (Table 2). Over all studies the weighted standardized effect was $d_+ = 2.874 \pm 0.098$ (95% confidence: 2.672, 3.056), indicating a significant

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Table 1. Descriptive information for comparing strawberry genotypes on methyl bromide : chloropicrin (MB:CP) fumigated soils vs. nonfumigated (NF) soils or on soils treated with chloropicrin (CP), dichloropropene: chloropicrin (DP:CP), or metam sodium.

Study no.	Test year	Location	Cultivars/ selections	Crop	Treatment ^a	Rate/ha	Reference	Study set ^b
1	1987	Watsonville	Chandler	First NF	NF	---	Welch, unpublished	N
2	1988	Watsonville	Chandler	First DP:CP ^a and NF	NF 83 DP:17 CP	666 kg	Welch, unpublished	N,D
3	1989	Watsonville	Chandler	Second NF	NF	---	Welch et al., 1990	N
4	1989	Watsonville	Chandler	Second NF	NF	---	Welch et al., 1990	N
5	1990	Watsonville	Chandler	Third DP:CP ^a and NF	NF 83 DP:17 CP	666 kg	Welch et al., 1991	N,D
6	1990	Watsonville	Chandler	Third NF	NF	---	Welch et al., 1991	N
7	1991	Watsonville	Selva	First DP:CP ^a and NF	NF 83 DP:17 CP	554 kg ²	Welch, unpublished	N,D
8	1992	Watsonville	Selva	First MS ^a	MS	842 L	Welch, unpublished	M
9	1993	Watsonville	12 UC cultivars/ selections	First NF	NF	---	Larson and Shaw, 1994	N
10	1993	Irvine	12 UC cultivars/ selections	First NF	NF	---	Larson and Shaw, 1994	N
11	1993	Irvine	Chandler	First CP and NF crop, 20-yr rotation	NF CP	112 kg	Larson and Sterrett, 1994	N,C
12	1993	Irvine	Oso	First CP and NF, 20-yr rotation	NF CP	112 kg	Larson and Sterrett, 1994	N,C
13	1993	Watsonville	Grande	Second NF	NF	---	Walsh et al., 1996	N
14	1994	Irvine	four UC cultivars	Second NF	NF	---	Larson, unpublished	N
15	1994	Irvine	Camaraosa	Second CP and NF	NF	---	Larson, unpublished	N,C
16	1994	Irvine	six UC cultivars	CP	336 kg	---	Larson et al., 1996	N,C
17	1994	Irvine	Chandler	Second CP and NF	NF CP	336 kg	Larson, unpublished	N,C
18	1994	Watsonville	Selva	First CP and NF	NF CP	336 kg	Larson, unpublished	N,C
19	1994	Watsonville	Selva	First CP and NF	NF CP	336 kg	Larson, unpublished	N,C
20	1994	Watsonville	Selva	First CP and NF	NF CP	336 kg	Larson, unpublished	N,C
21	1994	Oxnard	Chandler	First DP:CP ^a , CP ^a , MS ^a and NF	NF CP 7 DP:3 CP	396 kg 556 kg	Paulus, unpublished	N,C, D,M
22	1994	Watsonville	MS	917 L	NF	---	Shaw, unpublished	N
23	1994	Watsonville	12 UC cultivars/ selections	First NF	NF	---	Shaw, unpublished	N
24	1994	Watsonville	Selva	First CP ^a and NF	NF CP	231 kg	Welch et al., 1995	N,C
25	1995	Irvine	Chandler	Second CP	NF CP	336 kg	Larson, unpublished	N,C
26	1995	Irvine	Chandler	and NF crop	CP	---	Larson, unpublished	N
27	1995	Irvine	Chandler	Second NF	NF	---	Larson, unpublished	C
28	1995	Irvine	Chandler	Second CP	CP	336 kg	Larson, unpublished	N
29	1995	Irvine	Camaraosa	Second NF	NF	---	Larson, unpublished	N,C
30	1995	Watsonville	Selva	Second CP and NF	NF CP	336 kg	Larson, unpublished	N,C
31	1995	Watsonville	Selva	Second CP and NF	NF CP	336 kg	Larson, unpublished	N,C
32	1995	Oxnard	Chandler	First DP:CP ^a , CP ^a and NF	NF CP 7 DP:3 CP	539 kg	Paulus, unpublished	N,C, D
33	1995	Watsonville	nine UC cultivars	Second NF	NF	---	Shaw and Larson, 1996	N
34	1995	Watsonville	nine non-UC cultivars	Second NF	NF	---	Shaw and Larson, 1996	N
35	1995	Watsonville	12 UC cultivars/ selections	Second NF	NF	---	Shaw, unpublished	N
36	1996	Irvine	Camaraosa	Third CP	CP	336 kg	Larson, unpublished	C
37	1996	Irvine	Chandler, Nur. trt. ^a = low CP	Third CP	CP	336 kg	Larson, unpublished	C

continued on next page

Table 1. Continued.

Study no.	Test year	Location	Cultivars/ selections	Crop	Treatment ^a	Rate/ha	Reference	Study set ^b
38	1996	Irvine	Chandler, Nur. trt. ^c = NF	Third CP	CP	336 kg	Larson, unpublished	C
39	1996	Irvine	Camarosa	First CP crop after NF	CP	168 kg	Larson, unpublished	C
40	1996	Irvine	Chandler, Nur. trt. ^c = low CP	First CP crop after NF	CP	168 kg	Larson, unpublished	C
41	1996	Irvine	Chandler, Nur. trt. ^c = high CP	First CP crop after NF	CP	168 kg	Larson, unpublished	C
42	1996	Irvine	Chandler, Nur. trt. ^c = NF	First CP crop after NF	CP	168 kg	Larson, unpublished	C
43	1996	Irvine	Camarosa	Third NF	NF	---	Larson, unpublished	N
44	1996	Irvine	Chandler, Nur. trt. ^c = low CP	Third NF	NF	---	Larson, unpublished	N
45	1996	Irvine	Chandler, Nur. trt. ^c = high CP	Third NF	NF	---	Larson, unpublished	N
46	1996	Irvine	Chandler, Nur. trt. ^c = NF	Third NF	NF	---	Larson, unpublished	N
47	1996	Irvine	Camarosa	First MS ^a crop after NF	MS	935 L	Larson, unpublished	M
48	1996	Irvine	Chandler, Nur. trt. ^c = low CP	First MS ^a crop after NF	MS	935 L	Larson, unpublished	M
49	1996	Irvine	Chandler, Nur. trt. ^c = high CP	First MS ^a crop after NF	MS	935 L	Larson, unpublished	M
50	1996	Irvine	Chandler, Nur. trt. ^c = NF	First MS ^a crop after NF	MS	935 L	Larson, unpublished	M
51	1996	Watsonville	Selva	Second NF	NF	---	Larson, unpublished	N
52	1996	Watsonville	Selva	Second NF	NF	---	Larson, unpublished	N
53	1996	Watsonville	Selva	First CP	CP	336 kg	Larson, unpublished	C
54	1996	Watsonville	Selva	First CP	CP	168 kg	Larson, unpublished	C
55	1996	Watsonville	Selva	First CP	CP	336 kg	Larson, unpublished	C
56	1996	Watsonville	Selva	First CP and Second NF	NF	---	Larson, unpublished	C
57	1996	Watsonville	Selva	First CP	CP	224 kg	Larson, unpublished	C
58	1996	Oxnard	Chandler	First DP:CP, CP and NF crop	CP	168 kg	Larson, unpublished	C
					NF	---	Paulus, unpublished	N,C,D
					7 DP:3 CP	358 kg		
59	1996	Watsonville	12 UC cultivars/ selections	Second NF	NF	389 kg	Shaw, unpublished	N
60	1996	Watsonville	8 UC cultivars/ selections	First CP	CP	336 kg	Shaw, unpublished	C
61	1996	Watsonville	8 UC cultivars/ selections	First CP	CP	168 kg	Shaw, unpublished	C
62	1996	Watsonville	Selva	First MS ^a	MS	468 L	Larson, unpublished	M
63	1996	Watsonville	Selva	First MS ^a	MS	935 L	Larson, unpublished	M
64	1997	Watsonville	Selva	First DP:CP, Third NF	NF	---	Larson, unpublished	N,D
65	1997	Watsonville	5 UC cultivars/ selections	First DP:CP, Third NF	65 DP:35 CP	448 kg	Shaw, unpublished	N,D
					NF	---		
					65 DP:35 CP	448 kg		
66	1997	Irvine	Chandler	First DP:CP ^a and CP ^a , fourth NF	NF	---	Larson, unpublished	N,C,D
					CP	336 kg		
					65 DP:35 CP	386 kg		
67	1997	Irvine	Camarosa	First DP:CP ^a , CP ^a and NF	NF	---	Paulus et al., 1998	N,C,D
					CP	224 kg		
					4 DP:6 CP	392 kg		

^aMixtures of dichloropropene:chloropicrin were used at four rates. All trials were established using one of the treatments listed and 2 MB : 1 CP (wt:wt) with a rate of 392 kg·ha⁻¹; MB:CP rates differed for cases 21 (427 kg·ha⁻¹), 31 (405 kg·ha⁻¹), 58 (383 kg·ha⁻¹), 67 (57 MB : 43 CP @ 420 kg·ha⁻¹). All MS applications were performed using a formulation with 33.4% a.i.

^bStudies labeled N, C, D, and M were used in comparisons between MB:CP and NF (N), CP(C), DP:CP (D), and MS (M) alternatives.

^cFumigants applied using bed application methods. MB treatments were applied using bed application methods to studies 1-8, 21, 23, 31, 66, and 67.

^dNur. trt. = nursery fumigation treatment; low CP is 168-224 kg·ha⁻¹, high CP is 336-396 kg·ha⁻¹; NF is nonfumigated.

fumigation response for yield, and the overall unweighted increase in yield due to fumigation was 94.4%.

The difference between yields for plants in fumigated and NF soils increased over the first three strawberry cultivation cycles. Fumigation with MB:CP provided a standardized effect of $d_s = 2.166 \pm 0.146$ (59.2% yield advantage) for 17 studies where one cycle of fumigation was skipped or soil not recently cropped in strawberry was used, $d_s = 3.000 \pm 0.143$ (100.2% advantage) for 19 studies where strawberries were cultivated for two cycles without MB:CP fumigation, and $d_s = 6.201 \pm 0.348$ (148.4% yield advantage) in nine cases where strawberries were grown without soil fumigation for three or more cycles. Direct comparison of yields over cycles was not possible because the subsets of studies used different genotypes, harvest periods, etc. However, because nearly all the studies were conducted on ground that had been fumigated with MB:CP and cropped in strawberry for several prior cycles, the increase in d_s , or the change in relative yield advantage reported here over cycles, can be attributed to the reduction of yield with repeated cultivation in NF soils, rather than increases in yield due to serial fumigation with MB:CP. Because the 95% confidence limits for these three effect size estimates do not overlap, these results indicate significant yield reduction at each of the first three NF cultivation cycles, and the minimum productivity expected without soil fumigation has likely not been reached in the NF soil environments evaluated to date.

Results for the 34 individual studies comparing MB:CP fumigation with CP alone are summarized in Table 3. Yields following fumigation with MB:CP were larger than for CP fumigation in 28 of the 34 studies, and these differences were significant or highly significant in 12 of the 34 individual studies evaluated. Over all studies, the standardized effect was $d_s = 0.751 \pm 0.087$ (95% confidence: 0.581, 0.921), indicating a significant yield advantage for combinations of MB:CP over CP alone, and the overall unweighted increase in yield due to fumigation was 9.6%.

As a second step in evaluation of the CP alternative, the 34 studies were subdivided into a set of 23 studies where the rate of application was equal to or greater than 336 kg-ha⁻¹ CP, and a set of 11 studies with rates between 121 and 224 kg-ha⁻¹. At the higher application rate, the standardized effect was $d_s = 0.437 \pm 0.114$ (unweighted increase = 6.8%) whereas the lower application rate gave $d_s = 1.190 \pm 0.134$ (unweighted increase = 15.4%); 95% confidence limits for these subset effect sizes did not overlap, demonstrating a statistically significant dependence on application rate.

As a final step in comparing these two alternatives, the 23 studies in the high application rate subset were further subdivided based on the number of strawberry cultivation cycles between the last MB:CP treatment and the current evaluation. Similar to the case comparing MB:CP with NF, the difference between yields for plants in soils fumigated with a MB:CP mixture and soils treated with CP

Table 2. Effects of soil fumigation with methyl bromide : chloropicrin (MB:CP) vs. nonfumigated (NF) control studies on yields (grams/plant) of strawberry in 45 studies.

Study	No. reps	Treated		Nontreated		Increase ^a (%)	<i>t</i>	<i>p</i>	<i>d</i>
		Mean yield	SD	Mean yield	SD				
1	5	1007	74	502	63	100.6	11.62	<0.001	7.35
2	6	992	177	390	104	154.4	7.18	<0.001	4.15
3	6	916	136	384	167	138.5	6.05	<0.001	3.49
4	5	1720	82	710	135	142.3	14.30	<0.001	9.04
5	6	1331	40	463	112	187.4	17.87	<0.001	10.32
6	6	1734	212	713	117	143.2	10.32	<0.001	5.96
7	5	1069	110	619	122	72.7	6.12	<0.001	3.87
9	24	1480	359	752	173	96.8	8.95	<0.001	2.58
10	24	833	218	476	154	75.0	6.55	<0.001	1.895
11	18	763	80	557	116	37.0	3.58	0.003	2.07
12	18	772	64	535	95	44.3	5.07	<0.001	2.92
13	16	1239	62	529	46	134.2	36.79	<0.001	13.01
14	6	1704	44	1227	37	38.9	20.23	<0.001	11.73
15	24	1365	219	992	183	37.6	4.53	0.001	1.84
16	6	1423	106	1112	101	28.0	5.20	<0.001	3.00
17	4	1493	177	1149	332	30.0	1.83	0.055	1.29
18	4	1580	122	1328	233	19.0	1.92	0.048	1.36
19	5	1343	169	1118	148	20.0	2.24	0.026	1.42
20	5	1351	144	1227	390	10.1	0.67	0.259	0.42
21	6	886	71	503	50	76.0	10.82	<0.001	6.25
22	24	1346	252	1017	227	32.4	4.84	<0.001	1.40
23	5	1643	78	1012	81	62.4	12.55	<0.001	7.93
24	12	1369	191	891	102	53.6	7.65	<0.001	3.12
26	12	1415	158	989	113	43.1	6.12	<0.001	3.87
27	16	1449	172	651	94	122.5	11.52	<0.001	5.76
28	4	1397	192	400	70	249.3	9.76	<0.001	6.90
29	4	1553	135	571	137	172.0	10.21	<0.001	7.22
30	8	1352	286	595	140	127.2	6.72	<0.001	3.36
31	4	655	65	353	42	85.4	7.75	<0.001	5.48
32	18	1296	355	733	345	76.8	4.83	<0.001	1.61
33	18	578	310	263	207	119.8	3.59	<0.001	1.20
34	24	1602	276	792	157	102.3	11.70	<0.001	3.38
35	12	1460	59	521	77	180.2	33.53	<0.001	13.69
46	12	1282	55	511	56	150.9	34.02	<0.001	13.89
51	18	1357	114	760	90	78.5	17.43	<0.001	5.81
52	18	1503	241	708	166	112.2	11.53	<0.001	3.84
55	12	1648	66	547	116	201.3	28.58	<0.001	11.67
56	8	1540	89	887	136	73.6	11.36	<0.001	5.68
57	4	1401	80	528	127	165.3	11.63	<0.001	8.23
58	6	871	56	546	36	59.6	11.89	<0.001	6.86
59	24	1627	125	1058	112	53.8	16.61	<0.001	4.79
64	36	1381	146	759	118	81.9	19.88	<0.001	4.69
65	10	1742	131	955	152	82.4	12.40	<0.001	5.55
66	12	994	88	409	47	143.0	20.3	<0.001	8.29
67	4	610	46	465	46	31.2	4.46	<0.001	3.15

^aUnweighted percent increase in yield resulting from MB:CP treatment.

^b*t* is Student's *t* test value, *p* is a one-tailed probability (requires *P* < 0.025 for conventional significance), and *d* is the standardized effect size.

alone increased over the first three cultivation cycles: MB:CP fumigated soils provided a standardized effect of $d_s = 0.043 \pm 0.162$ (2.2% yield advantage for MB:CP) for 12 studies where one cycle of MB:CP fumigation was replaced by CP alone, $d_s = 0.588 \pm 0.174$ (10.6% advantage for MB:CP) for seven studies where strawberries were cultivated for two cycles with high rates of CP, and $d_s = 2.054 \pm 0.401$ (13.7% yield advantage for MB:CP) in four cases in which CP was used for three cycles. Although the initial yield decline after fumigation with high rates of CP was small, this appears largely the consequence of a carry-over effect of MB:CP fumigation for a single cycle; even on soils fumigated with high rates of CP yield declined as a new equilibrium was approached after more than one strawberry production cycle.

Yields for MB:CP-treated soils exceeded those for DP:CP treated soils in nine of the ten

individual studies reported here (Table 4), and individual differences were statistically significant in four of these nine cases. Over all 10 studies, the standardized effect was $d_s = 0.962 \pm 0.162$ (95% confidence: 0.645, 1.279), indicating a significant yield advantage for combinations of MB:CP over DP:CP combinations; the overall unweighted increase in yield due to fumigation with MB:CP was 14.4%. Performance of plants was statistically indistinguishable in soils fumigated with DP:CP mixtures and low rates of CP alone. Mixtures of DP:CP mixtures that use higher rates of CP might perform better on average, but there is no strong indication for this in the present set of studies.

Soil treatment with MS proved the least productive of the chemical alternatives tested, with yields for MB:CP treatments exceeding those for MS treated soils significantly in all eight individual studies (Table 5). Over all

eight studies the standardized effect was $d_s = 3.199 \pm 0.287$ (95% confidence: 2.637, 3.761), indicating a significant yield advantage for combinations of MB:CP over MS, and the overall unweighted increase in yield due to fumigation with the current industry standard was 29.8%. These results are consistent with the three studies eliminated because of insufficient data, where the average increase for MB:CP over MS was 29.0%. In fact, the standardized effect for this comparison did not differ significantly from the overall comparison of MB:CP mixtures with NF ($d_s = 2.874 \pm 0.098$), suggesting very little yield response following treatment with MS.

Discussion

The results of all meta-analyses are summarized in Table 6. For these studies, fumigation with a mixture of MB and CP increased yield significantly in comparison with any and all alternatives lacking MB. Mixtures of DP:CP that include a greater proportion of CP may provide a superior alternative to those tested here, although the deterioration of soil conditions for systems treated with high rates of CP alone over multiple cycles suggests that this likelihood is small. We conclude from this synthesis that there is no direct substitute for the current industry standard of preplant soil fumigation with mixtures of MB:CP. Furthermore, strawberry growers in California and other strawberry production locations with similar climate, using similar cultural tools, can expect yield reductions in excess of 10.5% because of changes in fruiting field fumigation practices alone if MB is eventually banned.

Yield reduction in the strawberry fruiting field is just one of many potential results of a regulatory elimination of MB. Of immediate and quantifiable consequence is the use of fumigation alternatives in runner propagation nurseries. Fumigation with MB:CP is practiced in such nurseries to enhance both plant production and quality (Larson and Shaw, 1995b) and to ensure a source of pest and disease free planting stock. Preliminary indications here are that use of planting stock from strawberry nurseries fumigated with realistic alternatives may reduce cumulative fruit yield substantially (Larson and Shaw, 1995b), even in the absence of lethal pathogens. Use of alternate fumigants will eventually impact the incidence of lethal pathogens in nursery and fruiting fields, and disease incidence may increase toward those levels experienced prior to widespread use of MB:CP (Wilhelm and Paulus, 1980).

Present-day cultural systems have evolved substantially during the past 50 years (Shaw, 1990; Voith and Bringham, 1990), and the trend has been toward an optimization relative to the superior soil environment provided by fumigation with MB:CP. Changes in fumigation practices that affect plant vigor and weed control can be expected to mandate changes in horticultural systems that in themselves will modify the magnitude and timing of strawberry fruit production. For example, alternatives deficient in weed control may require use

Table 3. Effects of soil fumigation with methyl bromide:chloropicrin (MB:CP) vs. chloropicrin (CP) on yields (grams/plant) of strawberry in 34 studies.

Study	No. reps	MB:CP treated		CP treated		Increase ^a (%)	r	p ^b	d ^c
		Mean yield	SD	Mean yield	SD				
11	18	763	80	768	84	-0.0	-0.10	0.538	-0.06
12	18	772	64	780	83	-1.0	-0.18	0.569	-0.11
15	24	1365	219	1283	286	6.4	0.79	0.219	0.32
16	6	1423	106	1233	252	15.4	1.70	0.060	0.98
17	4	1493	177	1477	162	1.2	0.13	0.451	0.09
18	4	1580	122	1528	76	3.4	0.72	0.248	0.51
19	5	1343	169	1371	390	-2.0	-0.15	0.558	-0.09
20	5	1351	144	1470	206	-8.1	-1.06	0.842	-0.67
23	5	1643	78	1502	141	9.4	1.96	0.043	1.24
24	12	1369	191	1227	110	11.6	2.23	0.018	0.91
26	12	1415	158	1316	125	7.5	1.70	0.052	0.69
27	6	886	71	823	70	7.7	1.56	0.075	0.90
28	4	1397	192	1303	77	7.2	0.91	0.197	0.64
29	4	1553	135	1270	234	22.3	2.10	0.040	1.48
30	8	1352	286	1304	381	3.7	0.28	0.392	0.14
31	4	655	65	598	96	9.3	0.95	0.190	0.67
35	12,6	1648	66	1409	99	17.0	4.92	<0.001	2.84
36	4,2	1401	80	1267	205	10.6	0.86	0.250	0.86
37	12,6	1460	59	1228	96	18.9	5.04	<0.001	2.91
38	12,6	1282	55	1185	74	8.2	2.58	0.011	1.49
39	12	1648	66	1235	100	33.4	11.94	<0.001	4.87
40	4	1401	80	1209	303	15.9	1.23	0.143	0.87
41	12	1460	59	1243	63	17.5	8.71	<0.001	3.56
42	12	1282	55	1068	52	20.0	9.79	<0.001	4.00
53	18	1358	114	1479	140	-8.2	-2.84	0.999	-0.95
54	18	1358	114	1168	125	16.3	4.76	<0.001	1.59
55	10	1540	90	1568	158	-1.7	-0.48	0.820	-0.22
57	10	1540	90	1316	138	17.0	4.29	<0.001	1.92
58	6	871	56	848	63	2.7	0.67	0.259	0.39
59	8	1627	125	1454	262	11.9	1.69	0.057	0.84
60	8	1627	125	1340	151	21.4	4.14	<0.001	2.07
64	36	1381	146	1204	176	14.7	4.64	<0.001	1.09
66	6	994	88	982	67	1.2	0.27	0.397	0.15
67	4	610	46	531	46	14.9	2.43	0.025	1.72

^aUnweighted percent increase in yield for the MB:CP treatment over the CP treatment group.

^br is Student's t test value, p is a one-tailed probability (requires $P < 0.025$ for conventional significance), and d is the standardized effect size.

Table 4. Effects of soil fumigation with methyl bromide:chloropicrin (MB:CP) vs. dichloropropene:chloropicrin (DP:CP) on yields (grams/plant) of strawberry in 10 studies.

Study	No. reps	MB:CP treated		DP:CP treated		Percent increase ^a	r	p ^b	d ^c
		Mean yield	SD	Mean yield	SD				
2	6	992	177	856	109	15.9	1.60	0.070	0.93
5	6	1331	40	1046	55	27.2	10.27	<0.001	5.93
7	5	1096	110	687	62	59.5	6.76	<0.001	4.28
21	6	886	71	914	48	-2.9	-0.78	0.727	-0.45
31	4	655	65	647	54	1.0	0.15	0.443	0.11
58	6	871	56	836	11	4.3	1.52	0.077	0.88
64	36	1381	146	1180	185	17.0	5.12	<0.001	1.21
65	10	1742	131	1489	141	17.0	4.16	<0.001	1.86
66	6	994	88	981	97	1.3	0.37	0.355	0.15
67	4	610	46	591	46	3.2	0.58	0.291	0.41

^aUnweighted percent increase in yield for the MB:CP treatment over the DP:CP treatment group.

^br is Student's t test value, p is a one-tailed probability (requires $P < 0.025$ for conventional significance), and d is the standardized effect size.

of colored plastic mulches which will delay fruiting and reduce total yield. Furthermore, changes in both soil fumigation environment and cultural practice affect fruit quality (Larson and Shaw, 1995a), which will ultimately determine the value of the crop produced. The consequences of these secondary effects must be quantified and their outcomes considered in evaluating the ultimate impact of MB regulatory policies on strawberry productivity.

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Table 5. Effects of soil fumigation with methyl bromide:chloropicrin (MB:CP) vs. metam sodium (MS) 153–305 L·ha⁻¹ a.i. on yields (grams/plant) of strawberry in eight studies.

Study	No. reps	MB:CP treated		MS treated		Percent increase ^a	t ^b	p ^c	d ^d
		Mean yield	SD	Mean yield	SD				
8	3	2126	47	1641	130	29.6	6.08	0.002	4.96
21	6	886	71	667	94	32.8	4.55	0.001	2.63
47	12	1648	66	1241	67	32.8	14.99	<0.001	6.12
48	4	1401	80	1184	119	18.3	3.03	0.012	2.14
49	12	1460	59	1270	51	15.0	8.44	<0.001	3.44
50	12	1282	55	1136	62	12.9	6.10	<0.001	2.49
62	8.5	1540	89	982	182	56.8	6.16	<0.001	3.90
63	8.5	1540	89	1100	190	40.0	4.69	<0.001	2.97

^aUnweighted percent increase in yield for the MB:CP treatment over the MS control group.

^bt is Student's t test value, p is a one-tailed probability (requires P < 0.025 for conventional significance), and d is the standardized effect size.

Table 6. Summary of meta-analysis comparisons presented in the text.

Comparison	No. studies	d _i (±se)	Increase with MB:CP (%)
Methyl bromide:chloropicrin vs. nonfumigated	45	2.874 ± 0.098	94.4
First nonfumigated cycle	17	2.166 ± 0.146	59.2
Second nonfumigated cycle	19	3.000 ± 0.143	100.2
Third nonfumigated cycle	9	6.201 ± 0.348	148.4
Methyl bromide:chloropicrin vs. chloropicrin	34	0.751 ± 0.087	9.6
High rate	23	0.437 ± 0.114	6.8
Moderate rate	11	1.190 ± 0.134	15.4
First chloropicrin cycle (high rate)	12	0.043 ± 0.162	2.2
Second chloropicrin cycle (high rate)	7	0.588 ± 0.174	10.6
Third chloropicrin cycle (high rate)	4	2.054 ± 0.401	13.7
Methyl bromide:chloropicrin vs. dichloropropene:chloropicrin	10	0.962 ± 0.162	14.4
Methyl bromide:chloropicrin vs. metam sodium	8	3.199 ± 0.287	29.8

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: Metam Na
[Insert Alternative]

Fumigant alternative to methyl brom:
Study: for polyethylene mulched tomato
[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

This alternative can be used on tomato, pepper, strawberry and
cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide****Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website?

Yes _____

No _____

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Lacascio, Gilreath, Dickson, Kucharek, Jones
and Noling

3. Publication and Date of Publication

HortScience, 1997

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

Metam Na

6. Was crop yield measured in the study?

Yes X

No _____

tomato

7. Describe the effectiveness of the alternative in controlling pests in the study.

The alternative was not very effective in controlling yellow and purple
nutsedge.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

We would expect similar results in North Carolina. This product must
be incorporated with a tractor mounted tillage for best results. However,
most growers do not have access to this equipment. Similar results would
be expected in pepper, strawberry and cucurbit crops.

Research Summary Table

Alternative: Metam-NaStudy: Locascio, Gilreath, Dickson, Kucharek, Jones and Noling, 1997

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (Gainesville)						Pest 2: Nutsedge (Bradenton)						Tomato Yield (tons/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		8 WAT	30					8 WAT	53					20.1 2.2
2	98/2 methyl bromide + chloropicrin	450 kg/ha	8 WAT	7					8 WAT	8					50.5 49.6
3	67/33 methyl bromide + chloropicrin	390 kg/ha	8 WAT	9					8 WAT	4					49.1 49.5
11	metam-Na	300 L/ha	8 WAT	32					8 WAT	56					22.6 8.3

Comments: Nutsedge density was plants per 0.1 m²; nutsedge = yellow and purple; 8 WAT = 8 weeks after treatment; Yield data = Gainesville | Bradenton, Florida.

03-0041

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
metam-Na	nutsedge	metam-Na	4.26 lbs./gal	300 lbs/ha	36	gal	\$ 4.00	\$ 90.00	80	100	1	\$ 314.00
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 314.00

Comments: Hand removal of nutsedge would be impossible with this weed and would likely cost over \$2,000 per acre.

Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

ID# _____

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a <i>representative</i> user.					
The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.					
Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.				
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.				
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.				
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.				
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.				
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the				
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.					
A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 pounds)	731.34 (Gainesville)	\$ 6.50	\$ 4,753.71
			300.95 (Bradenton)	\$ 6.50	\$ 1,956.18
					\$ 6,709.89
				Total Revenue	\$ 3,354.95
Comments: Hand removal would be impossible due to time and labor restraints.					

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:**Metam-Na**

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item.	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25			\$ 15.00	Tractor w/ mounted tiller
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

Fumigant Alternatives to Methyl Bromide for Polyethylene-mulched Tomato

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Additional index words. *Lycopersicon esculentum*, chloropicrin, 1,3-dichloropropene, metam-sodium, dazomet, tetrathiocarbonate, pest control, nematodes, fungi, weed control

Abstract. Tomato (*Lycopersicon esculentum* Mill.) was grown to evaluate various chemicals as possible alternatives to methyl bromide soil fumigation. Due to a combination of weeds, nematodes, and soil fungi, the use of a broad-spectrum fumigant has been essential for economical tomato production in Florida. Methyl bromide (MBR) and combinations of MBR with chloropicrin (Pic) are the fumigants of choice for most growers using polyethylene mulch culture. In 1991, MBR was allegedly associated with stratospheric ozone depletion. The U.S. Environmental Protection Agency has since mandated a phaseout of MBR for soil fumigation in the United States by the year 2001. At three locations in Florida, alternative soil fumigants were evaluated, including soil injected 98% MBR-2% Pic at 450 kg-ha⁻¹, 67% MBR-33% Pic (390 kg-ha⁻¹), Pic (390 kg-ha⁻¹), dichloropropene + 17% Pic (1,3-D + Pic) at 327 L-ha⁻¹, and metam-sodium (935 L-ha⁻¹). Also, metam-sodium and tetrathiocarbonate (1870 L-ha⁻¹) were applied by drip irrigation. Dazomet (450 kg-ha⁻¹) was surface applied and soil incorporated. Pebulate (4.5 kg-ha⁻¹) was soil incorporated with some treatments. Pic and 1,3-D + Pic treatments provided good to moderate control of nematodes and soil fungi except in one of the six studies, in which nematode control with 1,3-D was moderate to poor. Nutsedge densities were suppressed by addition of pebulate. Tomato fruit yields with 1,3-D + Pic + pebulate and with Pic + pebulate at the three sites ranged from 85% to 114%, 60% to 95%, and 101% to 119%, respectively, of that obtained with MBR treatments. Pest control and crop yield were lower with treatments other than the above pebulate-containing or MBR-containing treatments. These studies indicate that no one alternative pesticide can provide the consistent broad-spectrum control provided by MBR. Chemical names used: trichloronitromethane (chloropicrin); 1,3-dichloropropene (1,3-D); sodium N-methyldithiocarbamate (metam-sodium); sodium tetrathiocarbonate (tetrathiocarbonate); 3,5-dimethyl-(2H)-tetrahydro-1,3,5-thiadiazine-2-thione (dazomet); S-propyl butyl(ethyl)thiocarbamate (pebulate).

Tomato and bell pepper (*Capsicum annuum* L.) are the two most valuable vegetables grown for fresh-market production in Florida (Geuder and Pugh, 1996). During the 1994-95 crop season, tomato was grown on 19,845 ha and had an on-farm value of \$461 million, and

pepper was grown on 8,200 ha with a value of \$189 million. These two crops accounted for 44% of the monetary value of the vegetable industry in Florida with an average value of \$23,200/ha.

Tomatoes require intense management, including the use of broad-spectrum soil fumigants, polyethylene mulch, and adequate rates of fertilizer, irrigation, and pesticides. Before the use of black polyethylene as a mulch for these crops, most production occurred on new land to avoid or minimize competition from various soil pathogens and weeds. In the early 1970s, most Florida growers were using polyethylene mulch and a broad-spectrum fumigant, which resulted in large increases in yield

over that attained without their use. The fumigants of choice, because of their high efficacy and relatively low cost, are methyl bromide (MBR) and MBR-chloropicrin (Pic) combinations. Typical soils where most vegetables are grown in the southeastern United States have serious soilborne pathogens and pests, including plant-parasitic nematodes, fungi, bacteria, and weeds. Lack of control of any one of these can result in a reduction in yield and quality of fruit. Over the past 25 years, MBR and MBR-Pic combinations became the standard fumigants used with polyethylene-mulched vegetables because they were highly efficacious (Overman and Martin, 1978). Methyl bromide is considered one of the most important preplant soil fumigants available (Noling and Becker, 1994).

In 1992, MBR was alleged to contribute to the depletion of the stratospheric ozone layer (Watson et al., 1992). The U.S. Environmental Protection Agency has established regulations that call for a phaseout of MBR in the United States by 1 Jan. 2001 (U.S. Environmental Protection Agency, 1993). Broad-spectrum control of soilborne pests and pathogens to the degree provided by MBR has not been possible with other currently available fumigants (Methyl Bromide Technical Options Committee, 1995). Chloropicrin is effective against many soilborne diseases but is less effective against nematodes than MBR. The nematocide 1,3-D provides control of nematodes but is not an effective soil fungicide or herbicide. Control of purple and yellow nutsedges (*Cyperus rotundus* L. and *C. esculentus* L.) is not provided by either Pic or 1,3-D (Gilreath et al., 1994); however, these nutsedges must be controlled because both species are very serious weed pests that can easily grow through polyethylene mulch and reduce yields (Locascio et al., 1994).

For economic production of tomato, control of soil pathogens and weeds are essential. With the pending loss of MBR, studies were conducted with polyethylene-mulched tomatoes to evaluate other available preplant fumigants or combinations of chemicals as possible alternatives to MBR.

Materials and Methods

Polyethylene-mulched tomato was grown with drip irrigation at two sites on Millhopper fine sands (Grossarenic Paleudults, loamy, siliceous, hyperthermic) near Gainesville, Fla., during Spring 1994 and 1995, and near Bradenton, Fla., with seep irrigation on an Eau Gallie fine sand (Alfisol Haplaquods, sandy, siliceous, hyperthermic) in Spring and Fall 1994. Sites in Gainesville were at the Horticultural Unit and the Green Acres Research Farm. Fields at the Horticultural Unit were heavily infested with purple and yellow nutsedges, and moderately infested with the root-knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood and various soil fungi. The Green Acres site was heavily infested with *Meloidogyne arenaria* (Neal) Chitwood race 1, the peanut root-knot nematode. Sites at Bradenton were heavily infested with purple

nutedge, moderately to heavily infested with fusarium wilt (*Fusarium oxysporum* Schlecht. f. sp. *lycopersici* (Sacc.) Snyder and Hans. race 3), and lightly infested with the root-knot nematode *M. incognita*. Treatments included six to 12 fumigants applied during the various seasons with treatments arranged in randomized complete-block designs with six replications. Plots were single rows with 0.9-m-wide bed tops with beds spaced 1.8 m apart and 12 m long at Gainesville and 1.5 m apart and 15.4 m long at Bradenton.

After the initial soil preparation, beds at Gainesville were formed and fertilizer (58N-8P-50K kg-ha⁻¹) was applied in the bed along with the specified soil-applied fumigant and herbicide treatments. Black 0.038-mm-thick polyethylene mulch was then applied over the bed top. Double-wall drip tubing (Chapin Twinwall, Watertown, N.Y.), with emitters spaced 23 cm apart and a flow rate of 62 mL-min⁻¹, was placed 7.5 to 10 cm from the bed center under the mulch for application of water, fertilizer, and fumigants. Postplant fertilizer (144N-130K kg-ha⁻¹ as NH₄NO₃ and KCl) was applied with the irrigation water in 10 weekly applications. At Bradenton, fertilizer (34N-20P-37K kg-ha⁻¹) was applied to the soil and then a prebed was formed. Herbicide and fumigant treatments were applied and a final bed was formed and pressed with fertilizer (247N-284K kg-ha⁻¹) applied in two bands 30 cm from each side of the plant row immediately before application of the polyethylene mulch (black mulch in the spring and white mulch in the fall). Drip tubing identical to that used in Gainesville was placed in appropriate plots 10 cm from the west side of the bed center to allow delivery of drip-applied fumigants. The crop was irrigated with a semi-enclosed, subsurface irrigation system.

Soil fumigants at labeled rates were injected with three chisels per bed spaced 30 cm apart at a depth of 15 to 20 cm. Injected treatments were 98%-2% MBr-Pic (450 kg-ha⁻¹), 67%-33% MBr-Pic (390 kg-ha⁻¹), Pic (390 kg-ha⁻¹), and 1,3-D + 17% Pic (327 L-ha⁻¹). Pebulate (for nutsedge control) was applied on the bed surface and incorporated 15 to 20 cm deep with a roto-tiller before the fumigants were injected. Dazomet (440 kg-ha⁻¹ from a 92% formulation) and metam-sodium (300 L-ha⁻¹ from a 32% formulation) were applied on the bed surfaces and immediately incorporated. At the Horticultural Unit site, dazomet also was incorporated and then watered into the soil with 6 mm depth of water before mulch application. Metam-sodium (300 L-ha⁻¹) and tetrathiocarbonate (1870 L-ha⁻¹) were applied through two drip tubes spaced 30 cm apart per bed at Gainesville, and one drip tube at Bradenton. Tomato was transplanted into the treated soil 3 weeks after fumigant application. Two additional applications of tetrathiocarbonate (187 L-ha⁻¹) were made through the drip irrigation system during the crop growth period at Gainesville and Bradenton.

Tomato plants were set 0.5 m apart in the bed at all sites. 'Sunny' tomato was transplanted in 1994 on 4 Apr. at the Horticultural

Unit and on 6 Apr. at Green Acres. 'AgriSet 761' transplants were set on 28 Mar. 1995 at the Horticultural Unit and on 29 Mar. 1995 at Green Acres. 'Sunbeam' plants were transplanted on 7 Mar. 1994 and 'Sunny' plants were set on 18 Oct. 1994 at Bradenton. Drip irrigation was supplied at 0.75 times pan evaporation throughout both seasons at Gainesville. Subsurface irrigation was continuous at Bradenton to maintain a water table at 46 cm from the bed surface. Tomato plants were pruned by removal of the two lower branches and staked. Foliar insecticides and fungicides were applied weekly beginning 3 weeks after transplanting.

Tomato roots were assessed for the presence of fungi in mid-June of each season at the two Gainesville sites. One typical-appearing, randomly selected tomato plant and root system in each plot was removed from the field. The plants were brought to the laboratory where the soil was washed off the roots. Roots from each plant were excised and placed in an individual container where they were surface-disinfected with a 10% solution (v/v) of bleach (5.25%) for 1 min. Roots were then rinsed twice with sterile distilled water. Three clumps of roots, each weighing 0.25 to 0.35 g, from each plant were placed on acidified potato dextrose agar within each of three petri dishes. Beginning 2 d after plating and up to 9 d after plating, the incidence of all fungi associated with each root clump was assessed. At Bradenton, *Fusarium* wilt race 3 infected plants were enumerated weekly.

After harvest, six plants per plot were collected for assessment of nematode galling of the root system at Gainesville and all of the plants per plot were assessed at Bradenton. A galling index of 0 to 10 was used with 0 = 0 galls, 1 = <10% of roots galled, 2 = 20%, ..., 10 = 100% of the roots galled (Barker et al., 1986).

Counts of emerged nutsedge plants growing through the polyethylene mulch were made ~8 weeks after transplanting in an area of 0.095 m². Counts were made on the drip-tubing side of the plots at the Horticultural Unit. At Bradenton, nutsedge plants that emerged through the mulch film were counted in four randomly selected areas on each side of the plant row in each plot and numbers per plot were averaged.

Fruit were harvested twice at the mature green stage and graded into marketable size categories of extra-large, large, and medium fruits by U.S. grade standard (U.S. Dept. of Agriculture, 1976). Data were subjected to analysis of variance with treatment means separated by Duncan's multiple range test (SAS, 1995).

Results and Discussion

Marketable fruit yield. Marketable yields of fruit were influenced by fumigant treatments in all seasons and at all locations (Table 1). Fruit yields were higher than control values and statistically similar among treatments with MBr98-2, MBr67-33, Pic+pebulate, and 1,3-D + Pic + pebulate, except at the 1994 Green

Acres site, where the pebulate-containing treatments did not perform as well as the two MBr treatments. During the 1994 fall study at Bradenton, yields with all fumigant treatments were similar and significantly higher than with no fumigant. At the two Gainesville sites, marketable yields varied from intermediate to no higher than the no fumigant treatments with Pic, 1,3-D + Pic, dazomet, dazomet+pebulate, metam-sodium, and metam-sodium+pebulate.

Relative fruit yield with the two MBr treatments was designated as 100% at each site. At the Horticultural Unit site in 1994, relative yields with the Pic+pebulate and with the 1,3-D + Pic + pebulate treatments were 86% and 85%, respectively, and in 1995 they were 114% and 102%, respectively. At Green Acres, relative yields with the two pebulate-containing treatments in 1994 were 60% and 77%, respectively, and in 1995 were both 95%. At Bradenton, relative yields with these two treatments ranged from 101% to 119% during the spring and fall seasons, respectively. In contrast to the fair to excellent production obtained with the two pebulate-containing treatments at the Horticultural Unit in 1994, relative yields were 60% to 70% with Pic, 1,3-D + Pic, dazomet, and metam-sodium drip applied, 45% with soil applied metam-sodium, 47% with tetrathiocarbonate, and 40% with no treatment. Similarly, at Bradenton, yields were reduced with alternative fumigants alone, but where pebulate was combined with fumigants other than metam-sodium in Spring 1994, yields were equal to that with MBr-Pic-containing treatments.

Control of soil fungi. Three predominant pathogenic fungi, *Rhizoctonia solani* Kuhn, *Macrophomina phaseolina* Tassi (Goidanich), and *Fusarium solani* (Mart) Sacc. (emend Snyder and Hans.), were recovered from tomato roots at the two Gainesville sites. Both *R. solani* and *M. phaseolina* are reported as pathogens of tomato (Jones et al., 1991). At Gainesville, the total numbers of colonies of these three fungi isolated from roots were significantly reduced by MBr98-2 and MBr67-33 in all studies, by five of six treatments with Pic alone and Pic + pebulate, and by four of seven treatments with 1,3-D + Pic and 1,3-D + Pic + pebulate, as compared with no treatment (Table 2). Dazomet, metam Na, and tetrathiocarbonate treatments did not significantly reduce the number of fungal colonies recovered. Use of Pic alone or in combination with 1,3-D reduced total fungal counts in nine of the 13 treatments. Pic is generally regarded as being more potent than MBr, but in these studies, treatments with MBr (98-2 and 67-33) provided higher consistency for reducing fungal infections than did those with Pic without MBr (2% Pic). At Bradenton (plots were infested with *Fusarium* wilt race 3), use of all fumigants significant reduced the percentage of plants infected.

Nematode control. At the Horticultural Unit site, root-knot nematode galling indices were significantly lower with soil treatments of MBr98-2, MBr67-33, and 1,3-D + Pic alone and + pebulate than with no fumigant treatment (Table 3). Galling indices were interme-

Table 1. Marketable fruit yield of tomato as influenced by various fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Marketable yield (t·ha ⁻¹) ^a					
		Gainesville				Bradenton	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		20.1 f [*]	20 e	26.5 de	25.9 e	2.2 d	17.4 b
MBR-Pic 98-2%	450 kg	50.5 a ✓	44 ab	48.2 a	47.8 a	49.6 a	— [*]
MBR-Pic 67-33%	390 kg	49.1 a	42 a-c	45.8 a	45.6 a	49.5 a	32.1 a
Chloropicrin (Pic)	390 kg	30.8 c-e ✓	—	34.6 bc	—	26.2 b	—
Pic + pebulate [*]	390 + 4.5 kg	43.0 ab	49 a	28.0 c-e	44.4 ab	—	38.2 a
1,3-D + 17% Pic (C-17)	327 L	34.6 bc	—	33.7 cd	27.4 b	—	—
1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	42.5 ab	44 ab	36.2 b	44.4 ab	50.2 a	34.2 a
Dazomet	440 kg	32.2 cd	—	25.3 e	—	26.9 b	—
Dazomet + 6 mm irrigation	440 kg	30.9 c-e	—	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— [*]	36 cd	—	41.2 a-c	—	30.8 a
Metam Na	300 L	22.6 ef ✓	—	30.4 c-e	—	9.3 cd	—
Metam Na + pebulate	300 L + 4.5 kg	—	33 d	—	34.5 cd	23.9 bc	32.3 a
Metam Na (drip)	300 L	32.3 cd ✓	—	29.8 c-e	—	23.1 bc	—
Tetrathiocarbonate (drip)	1870 L	23.7 ef	—	23.8 e	—	3.6 d	—

^aMarketable fruit included size categories with mean mass of extra-large 205 g, large 150 g, and medium 115 g.^{*}Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.^{*}Treatment not applied.^{*}Pic applied at 375 kg in 1995 at Green Acres.

Table 2. Total fungi infecting tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Gainesville (total fungal colonies/plant sample) ^a				Bradenton (<i>Fusarium</i> wilt, % plants infected) ^b	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		11.3 a [*]	14.3 a	8.0 a	15.5 a	40 a	23 a
MBR-Pic 98-2%	450 kg	3.3 d	4.3 c	2.0 b	8.0 bc	0 c	— [*]
MBR-Pic 67-33%	390 kg	4.8 cd	4.3 c	2.3 b	3.0 c	0 c	0 b
Chloropicrin (Pic)	390 kg	4.3 cd	—	4.3 ab	—	4 c	—
Pic + pebulate [*]	390 + 4.5 kg	4.5 cd	4.3 c	3.0 b	4.0 bc	—	0 b
1,3-D + 17% Pic	327 L	5.0 b-d	—	5.3 ab	8 bc	—	—
1,3-D + 17% Pic + pebulate	327 L + 4.5 kg	2.8 d	3.8 c	4.0 ab	3.5 c	4 c	0 b
Dazomet	440 kg	10.0 ab	—	2.7 b	—	4 c	—
Dazomet + 6 mm irrigation	440 kg	10.3 a	—	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— [*]	8.7 a-c	—	7.0 bc	—	0 b
Metam Na	300 L	11.3 a	—	4.0 ab	—	8 bc	—
Metam Na + pebulate	300 L + 4.5 kg	—	6.8 c	—	3.3 c	4 bc	0 b
Metam Na (drip)	300 L	6.5 a-d	—	3.3 b	—	20 b	—
Tetrathiocarbonate (drip)	1870 L	8.8 a-c	—	8.0 a	—	12 bc	—

^aTotal fungi infecting tomato roots included *Rhizoctonia solani*, *Macrophomina phaseolina*, and *Fusarium* spp.^bPlants infected with *Fusarium oxysporum* f. sp. *lycopersici*.^{*}Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.^{*}Treatment not applied.^{*}Pic applied at 375 kg in 1995 at Green Acres.

Table 3. Nematode gall rating of tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nematode gall index ^a				Bradenton Spring 1994
		Gainesville		Green Acres		
		Horticultural Unit				
		1994	1995	1994	1995	
Nontreated	4.5 a [*]	5.3 a	8.9 ab	8.9 a	2.8 ab	
MBR-Pic 98-2%	450 kg	1.0 b	0.2 c	4.1 e	1.1 c	0.2 b
MBR-Pic 67-33%	390 kg	1.2 b	0.4 c	3.6 e	1.4 c	0.2 b
Chloropicrin (Pic)	390 kg	4.3 a	— ^a	8.5 ab	—	0.2 b
Pic + pebulate [*]	390 + 4.5 kg	3.5 a	0.9 c	8.7 ab	5.8 b	—
1,3-D + 17% Pic	327 L	1.2 b	—	6.3 cd	0.2 b	
1,3-D, 17%Pic + pebulate	327 L + 4.5 kg	1.0 b	0.5 c	6.6 cd	2.6 c	0.8 b
Dazomet	440 kg	3.2 ab	—	7.4 bc	—	2.0 ab
Dazomet + 6 mm irrigation	440 kg	3.9 a	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— ^a	2.1 bc	—	3.5 c	—
Metam Na	300 L	3.2 ab	—	9.0 ab	—	4.4 a
Metam Na + pebulate	300 L + 4.5 kg	—	3.9 b	—	7.9 b	2.2 ab
Metam Na (drip)	300 L	3.8 a	—	4.9 de	—	2.8 ab
Tetrathiocarbonate (drip)	1870 L	4.2 a	—	9.7 a	—	3.4 ab

^aRoot-knot gall indices 0–10 with 0 = no galls, ..., 10 = 100% of root system galled.^{*}Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.^{*}Treatment not applied.^{*}Pic applied at 375 kg in 1995 at Green Acres.

diate with dazomet + pebulate, and with metam-sodium + pebulate, but were significantly lower than with no fumigant treatment. In 1994, Pic and Pic + pebulate had no significant effect on galling index. At Green Acres in both seasons, root-knot nematode galling indices were reduced most consistently with MBr treatments. Moderate nematode control was provided with 1,3-D + Pic alone or with added pebulate and with metam Na (drip applied) in 1994. Nematode control was similar to that with the no fumigant treatment with Pic, Pic + pebulate, dazomet, metam Na, and tetrathiocarbonate. At Bradenton, nematode counts were low even with the nonfumigated treatments, and root galling indices were not significantly affected by treatment.

Nutsedge control. Nutsedge was a major weed pest at the Horticultural Unit in Gainesville and at the Bradenton site where densities were heavy and very heavy, respectively. At Gainesville, counts of emerged nutsedge seedlings were made ~8 weeks after transplanting tomato (Table 4). Nutsedge population densities were higher on the drip tubing side of the bed than on the opposite and drier side of the bed (data not shown). Nutsedge counts with no treatment on the tubing side of the bed near the end of the two seasons were 30 and 16 plants per 0.1 m², respectively (Table 4). Nutsedge counts during 1994 were low (number in parenthesis) per 0.1-m² area with MBr 98-2 (7), MBr 67-33 (9), Pic + pebulate (11), and with 1,3-D + Pic + pebulate (15). Counts were higher with Pic (22) and 1,3-D + Pic (34). Nutsedge control was poor with the other treatments and emerged numbers were similar to those obtained with no treatment. During the 1995 season, nutsedge counts per m² averaged 3 with the two MBr treatments, 4.5 with the pebulate-containing treatments, and 16 with no treatment. During the Spring 1994 study at Bradenton, the combination of 1,3-D + Pic + pebulate and metam-sodium + pebulate provided nutsedge control as good as that obtained with either MBr 98-2 or MBr 67-33. Nutsedge control with other treatments was poor. In the Fall 1994 study, the combination of pebulate with each of the alternative fumigants provided nutsedge control equal to that obtained with the MBr treatments.

Marketable fruit yield correlated negatively with nutsedge number, root-knot nematode galling indices, and total fungal colonies in roots. In these studies, two treatments, Pic + pebulate, and 1,3-D + Pic + pebulate, suppressed nutsedge, nematode galling, and total fungi comparable to the suppression provided by the standard MBr treatments in most studies.

Data from these studies indicate that multiple pests adversely affect tomato production and that the initial level of these pests influences the degree of control obtained by the

Table 4. Nutsedge growing through polyethylene mulch on tomato beds as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nutsedge (plants/0.1 m ²)			
		Gainesville		Bradenton	
		Horticultural Unit		Spring	Fall
		1994	1995	1994	1994
1 Nontreated		30 a-c	16 a ¹	53 ab	22 a
2 MBr-Pic 98-2%	450 kg	7 e ✓	2 c	8 d ✓	—
3 MBr-Pic 67-33%	390 kg	9 e ✓	4 c	4 d	1 b
4 Chloropicrin (Pic)	390 kg	22 b-d x	—	60 ab x	—
5 Pic + pebulate ²	390 + 4.5 kg	11 e	2 c	—	6 b
6 1,3-D + 17% Pic	327 L	34 a x	—	66 a x	—
7 1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	15 de	3 c	5 d	7 b
8 Dazomet	440 kg	31 ab	—	37 c	—
9 Dazomet + 6 mm irr.	440 kg	25 a-c	—	—	—
10 Dazomet + pebulate	440 + 4.5 kg	—	3 c	—	6 b
11 Metam Na	300 L	32 a x	—	56 ab <	—
12 Metam Na + pebulate	300 L + 4.5 kg	—	10 b	7 d	5 b
13 Metam Na (drip)	300 L	22 cd x	—	51 b x	—
14 Tetrathiocarbonate (drip)	1870 L	33 a	—	54 ab	—

¹Mean separation by Duncan's multiple range test, $P \leq 0.05$

²Treatment not applied.

³Pic applied at 375 kg in 1995 at Green Acres.

fumigants. Although no one pesticide provided the broad-spectrum and consistent control provided by MBr, a combination of chemicals did provide similar control in some studies. Pest control and fruit yields were lower with dazomet, metam Na, and tetrathiocarbonate treatments than with the MBr treatments. Where high populations of nutsedge were present, pebulate provided partial control of this weed and, when combined with 1,3-D + Pic or Pic, resulted in sufficient plant growth to obtain 85% to 100% of the yield produced with MBr. In studies where nematodes and fungi populations were high and not adequately controlled, relative yields with Pic + pebulate and with 1,3-D + Pic + pebulate were as low as 60% of that produced with the MBr treatments. With the high cost to produce tomato, this level of yield would not be adequate for long-term sustainable production. For these alternative fumigants to be acceptable, factors that influence the inconsistent control of nematodes and soil fungi at some sites must be determined. Later work at Green Acres indicated that nematode control with 1,3-D + Pic was enhanced by deeper injections to 20 to 30 cm (data not shown) as compared to the 20-cm depth used in the present study. Additional studies on the influence of fumigant rate and placement should provide enhanced control of these pests.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: Metam Na + pebulate
[Insert Alternative]

Study: Alternative fumigants applied with PE and VIF mulches for tomato
[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

Can be used in tomato, pepper, strawberry and cucurbit crops.

Pebulate can not be used in crops other than tomato. Thus, nutsedge control is likely to be much less.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website?

Yes _____

No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Locascio and Dickson

3. Publication and Date of Publication

2001 Annual International Research Conf. on Methyl Bromide

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

Metam Na

6. Was crop yield measured in the study?

Yes X

No _____

tomato yield

7. Describe the effectiveness of the alternative in controlling pests in the study.

Metam Na was evaluated in tomatoes. It was not effective in controlling yellow and purple nutsedge.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Growers would not use this alternative because it is not effective, and it must be incorporated with a tractor mounted tillage which most growers do not have. Pebulate is not labeled in strawberry, cucurbit crops and pepper, thus, nutsedge control is likely to be much less. Similar results are expected in strawberry, cucurbit crops and pepper.

Research Summary Table

Alternative: Metam-NaStudy: Locascio and Dickson, 2001

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. al per area)	Pest 1: Yellow and purple nutsedge (no./m ²)						Pest 2						Tomato Yield (tons/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	untreated		124	215											20.0
2	67/33 methyl bromide + chloropicrin	235 kg/ha	124	18											62.7
3	67/33 methyl bromide + chloropicrin	390 kg/ha	124	23											67.0
10	metam-Na + pebutate	295 + 4.5 kg/ha	124	77											46.3

Comments:

03-0041

Metam-Na

Col. A: Name of Product and Non-chemical Control

Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.

Col. B: Target Posts

Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.

Col. C: Active Ingredients

Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.

Col. D: Formulation

Enter the formulation or the % of active ingredient.

Col. E, F, G: Application Rate

As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G. Use 2001 prices and costs. If the product is a mixture, indicate the percentage of active ingredient in Col. H.

Col. H, I, J: Prices and Costs

Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.

Col. K: Area Treated

Enter the area receiving at least one application of the pesticide.

Col. L: # of Applications per Year

Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an integer, it must be a whole number.

Col. M: Cost per Area in 2001

Enter the cost per acre in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per acre is known because the product was custom applied.

Non-chemical Control

Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical control in Col. C.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

[illegible]

03 - 0041

worksneer 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

ID#

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 pounds)	1,498.27	\$ 6.50	\$ 9,738.76
Comments:				Total Revenue	\$ 9,738.76

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

ID#

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25			\$ 15.00	Tractor w/ mounted tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments: Hand removal would be impossible and would amount to over \$2,000 per acre.

ALTERNATIVE FUMIGANTS APPLIED WITH PE AND VIF MULCHES FOR TOMATO

S. J. Locascio* and D. W. Dickson, Horticultural Sciences and Entomology and
Nematology Departments, University of Florida, Gainesville, FL 32611-0690.
and Erin Rosskopf, USDA-ARS, Fort Pierce, FL 34945-3138

In-row application of 1,3- dichloropropene (1,3-D) + 17% and 35% chloropicrin (Pic) at $336 \text{ L}\cdot\text{ha}^{-1}$ + pebulate at $4.5 \text{ kg}\cdot\text{ha}^{-1}$ are effective alternative for methyl bromide-Pic (MBr-Pic) for polyethylene mulched tomato. However, the use of 1,3-D products will be limited by the worker protection provisions required in handling this material. In contrast to in-row applications, broadcast applications minimizes the impact of these worker protection provisions on 1,3-D application. In past studies with tomato, pepper, and strawberry, metam-Na at the labeled rate of $295 \text{ L}\cdot\text{ha}^{-1}$ has not provided acceptable control of weeds, nematodes, and soil fungi. However, pest control has been adequate at $590 \text{ L}\cdot\text{ha}^{-1}$ in limited studies. Thus, a broadcast application rototilled and pressed into the bed area would concentrate metam-Na and should improve pest control. The experimental fumigant, iodomethane-Pic (MI) may be as effective as MBr-Pic. Volatility of all fumigants to the atmosphere is a concern. The development of high density polyethylene (HDPE) mulches that are virtually impermeable films (VIF) may reduce emission of fumigants and improve fumigant activity.

Tomato (*Lycopersicon esculentum* Mill.) was grown during Spring 2001 to evaluate the effect of application method of fumigants applied with low-density polyethylene (LDPE) and VIF mulches on production and pest control. Studies were conducted on a Millhopper fine sand site near Gainesville, FL that was naturally infested with purple and yellow nutsedge (*Cyperus rotundus* L. and *Cyperus esculentus* L.), root-knot nematode [*Meloidogyne incognita* (Kofoed & White) Chitwood], and soil pathogenic fungi. Broadcast applications of 1,3-D + 35% Pic at $243 \text{ L}\cdot\text{ha}^{-1}$ and 1,3-D at $168 \text{ L}\cdot\text{ha}^{-1}$ were injected 0.25 m deep with 6 shanks spaced 0.3 m apart on 1.8m plots on 8 Feb. On 15 Feb., MBr-Pic (67-33%) and MI-Pic, each at 235 and $390 \text{ kg}\cdot\text{ha}^{-1}$, and 1,3-D + 35% Pic at 196 and $336 \text{ L}\cdot\text{ha}^{-1}$ were injected 0.25 m deep with 3 shanks spaced 0.3 m apart on 0.9 m beds, and metam-Na was sprayed onto 1.8 m plots, rototilled, and formed into 0.9 m wide beds. Beds (0.9 m) were formed and Pic at $311 \text{ L}\cdot\text{ha}^{-1}$ was injected into beds that had been broadcast treated with 1,3-D. Pebulate was applied on the bed and incorporated 0.1m at $4.5 \text{ kg}\cdot\text{ha}^{-1}$ with all treatments except MBr-Pic, MI-Pic, and the untreated control. One drip tubing line and $38.1\mu\text{m}$ (1.5 mil) black polyethylene (PE) or $35\mu\text{m}$ VIF (Industria Plastica Monregalese, Mondovi, Italy) mulches were applied on 15 Feb. On 28 Feb., metam-Na was applied at $295 \text{ L}\cdot\text{ha}^{-1}$ with 2 and 3 drip lines with 6 and 4 hours of water application, respectively. Treatments were arranged in a split-plot with 12 fumigant and 2 mulches with five replications in plots 1.8 m x 11.0 m. 'Florida 47' tomato seedlings were transplanted 0.45 m apart on the bed on 13 Mar. Fruit were harvest at the mature green stage and graded into marketable and cull fruit. A complete fertilizer was applied before

bedding and additional N-K fertilizer was applied through the drip-irrigation system. Purple and yellow nutsedge plants that grew through the mulch were counted at the middle and end of the season. After fruit harvest, 10 tomato plants per plot were dug, and roots were rated for the presence of root-knot nematodes. Two plants per plot were taken for root disease identification. Roots were washed and 6 g of root tissue was plated onto two plates each of three selective media for isolation of *Fusarium oxysporum*, *Pythium* spp., and general fungi. Plated tissue included crown tissue, lateral roots, and fine roots. The incidence (%) of the fungal genera isolated was calculated.

Tomato seedlings sampled five weeks after transplanting were affected by fumigant and mulch treatment (Table 1). Interactions between fumigant and mulch were not significant, therefore main effects are presented. Plant size was significantly greater with all fumigant treatments than with no treatment. Plant were larger and similar with both rates of MBr-Pic and significantly smaller with all other fumigant treatments except MI-Pic at the lower rate of 235 kg-ha⁻¹. The smallest plants were obtained with the in-row treatment of 1,3-D + 35% Pic at 196 L-ha⁻¹ and the broadcast treatment of 1,3-D + 35% Pic at 243 L-ha⁻¹. Overall, plant dry weights were 14 % smaller with the VIF mulch than with the PE mulch. This may indicate that the fumigants were held in the soil longer with the VIF and this resulted in some reduction in plant growth. Nutsedge counts made on 30 Mar. indicated excellent nutsedge control with all fumigants except with broadcast applied 1,3-D + 35% Pic + pebulate. The 1,3-D treatment applied broadcast with Pic and pebulate applied in the row provided excellent sedge control. At the 19 June sampling, nutsedge control was good with all treatments except with 1,3-D + 35% Pic and metam-Na applied broadcast, and with metam-Na applied with 2 drip lines. Mulch type had no effect on nutsedge counts. Root gall was not as severe at this site as in past work. The root gall ratings of 4.6 and 4.7 were highest with the check and with metam-Na applied broadcast, and lower and similar with all other fumigants (Table 1). The incidence of root *Fusarium oxysporum* was less than with the check all fumigants except with 1,3-D + 35% Pic in-row at 336 L-ha⁻¹ and applied broadcast, and with metam-Na broadcast and applied with 2 drip tubes.

Tomato total fruit yields with all fumigant treatments were higher than with no treatment (Table 1). Fruit yields were highest with 1,3-D treatment applied broadcast with Pic and pebulate applied in the row, all MBr-Pic and MI-Pic treatments, in row applied 1,3-D + 35% Pic at 196 L-ha⁻¹, and metam-Na applied with 3 drip lines. Fruit yields were significantly lower with broadcast applied 1,3-D + 35% Pic and broadcast metam-Na. Also, yields were significantly higher with PE than with VIF mulch.

In this study, neither yields or pest control was enhanced with VIF as compared to that with PE mulch. Loss of fumigant was probably reduced with VIF mulch compared with PE mulch but this was not measured. Also, pest control and yields were similar with the higher and lower rates of MBr-Pic and MI-Pic with both mulch types. Pest control and yields were lower with broadcast applied 1,3-D + 35% Pic than with in row applied 1,3-D + 35% Pic and with broadcast applied metam-Na. Drip applied metam-Na applied with 3

drip tubes provided better pest control and fruit yield than with 2 drip lines or applied broadcast and rototilled in to the bed.

Table 1. Main effects of fumigant and mulch on plant vigor, nutsedge counts, nematode, and Fusarium root ratings, and fruit yield of 'Fla 47 Tomato'. Gainesville, FL. Spring 2001. Interactions between fumigant and mulch were not significant.

Treatment	Rate/ha	Plant dw	Nutsedge		Root	Root	Yield
		g 19 Apr.	no./m ² 30 Mar.	19 June	gall ^u 12 Jul	Fusarium ^t 26 June	
1 Untreated		13f	58a	215a	4.6a	22.3ab	20.0e
2 Methyl bromide /Pic (67/33)	235 kg	34a	0c	18cd	1.6bc	9.1de	62.7abc
3 Methyl bromide /Pic (67/33)	390 kg	33ab	0c	23cd	1.4bc	3.3e	67.0ab
4 Iodomethane /Pic (67/33)	235 kg	29bc	1.	20cd	0.3bc	5.8de	63.7ab
5 Iodomethane /Pic (67/33)	390 kg	27cd	0c	17cd	0.2c	4.9de	67.2ab
6 1,3-D + 35 % Pic ^z	196 L	21e	0c	11d	2.2b	8.1cde	61.7abc
7 1,3-D + 35 % Pic ^z	336 L	26cde	2c	21 cd	1.5bc	13.9bcd	55.2bcd
8 1,3-D + 35 % Pic ^{yz}	243 L	22de	38b	227a	1.8bc	18.9abc	42.8d
9 1,3-D ^y + Pic ^z	168L + 311kg	28bcd	2c	20cd	0.2c	8.1cde	69.8a
10 Metam-Na ^{yz}	295 L	27cd	12c	77b	4.7a	26.4a	46.3d
11 Metam-Na ^z - Drip ^x	295 L	25cde	5c	66bc	1.8bc	11.5bcde	50.2cd
12 Metam-Na ^z - Drip ^w	295 L	25cde	0 c	32cd	1.2bc	9.1de	67.7ab
<u>Mulch film</u>							
Polyethylene		28a	10	69	2.0	12.6	59.1a
VIF		24b	10	55	1.5	10.9	53.3b
Signif.		**	ns	ns	ns	ns	*

^zPebulate applied at 4.5 kg/ha.

^yTreated broadcast.

- ^xTreated thru (2) drip lines with 6 hours water.
- ^wTreated thru (3) drip lines with 4 hours water.
- ^vMean separation Duncan's Multiple Range Test, 5 % level.
- ^uRoot ratings 0 (none) -10 (100 %).
- ^tIncidence (%) of *Fusarium oxysporum*.

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + 17% chloropicrin

[Insert Alternative]

Study: Fumigant alternatives to Methyl bromide for polyethylene-mulched

[Insert Study Title]

tomato

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted

X

1b. Township caps

1c. Alternative not acceptable in consuming country

1d. Other (Please describe)

Can be used on tomato, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website?

Yes _____

No _____

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Locascio, Gilreath, Dickson, Kucharek, Jones
and Noling

3. Publication and Date of Publication

HortScience, 1997

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

1,3-D 17% chloropicrin

6. Was crop yield measured in the study?

Yes _____

X

No _____

tomato

7. Describe the effectiveness of the alternative in controlling pests in the study.

This alternative was not effective in controlling yellow and purple
nutsedge.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

This study relates to our situation in North Carolina and we would expect
similar results in cucurbit crops, tomato and pepper.

Research Summary Table

Alternative: 1,3-D + 17% chloropicrin

Study: Locascio, Gilreath, Dickson, Kucharek, Jones and Nolting, 1997

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (Gainesville)						Pest 2: Nutsedge (Bradenton)						Tomato Yield (tons/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		8 WAT	30					8 WAT	53					20.1 2.2
2	methyl bromide + chloropicrin	450 kg/ha	8 WAT	7					8 WAT	8					50.5 48.2
3	methyl bromide + chloropicrin	390 kg/ha	8 WAT	9					8 WAT	4					49.1 45.8
6	1,3-D + 17% chloropicrin	327 L	8 WAT	34					8 WAT	66					34.6 33.7

Comments: Nutsedge density was plants per 0.1 m²; nutsedge = yellow and purple; 8 WAT = 8 weeks after treatment; Yield data = Horticultural Unit | Green Acres (Gainesville, Florida).

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If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gal)						
1,3-D	nutsedge		83%									
17% chloropicrin	nutsedge		17%		86.4	gal	13.10 gal	\$ 75.00	80	100	1	\$ 1,288.84
Non-Chemical Pest Control	Target Pests	Description										Cost/Area
											Total	\$ 1,288.84

Comments:

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

[illegible]

Comments: 1,100 is an average from two locations at Gainesville, Florida.

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

1,3-D + 17% chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No changes

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Fumigant Alternatives to Methyl Bromide for Polyethylene-mulched Tomato

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Abstract. Tomato (*Lycopersicon esculentum* Mill.) was grown to evaluate various chemicals as possible alternatives to methyl bromide soil fumigation. Due to a combination of weeds, nematodes, and soil fungi, the use of a broad-spectrum fumigant has been essential for economical tomato production in Florida. Methyl bromide (MBR) and combinations of MBR with chloropicrin (Pic) are the fumigants of choice for most growers using polyethylene mulch culture. In 1991, MBR was allegedly associated with stratospheric ozone depletion. The U.S. Environmental Protection Agency has since mandated a phaseout of MBR for soil fumigation in the United States by the year 2001. At three locations in Florida, alternative soil fumigants were evaluated, including soil injected 98% MBR-2% Pic at 450 g-ha⁻¹, 67% MBR-33% Pic (390 kg-ha⁻¹), Pic (390 kg-ha⁻¹), dichloropropene + 17% Pic (1,3-D + Pic) at 327 L-ha⁻¹, and metam-sodium (935 L-ha⁻¹). Also, metam-sodium and tetrathiocarbonate (1870 L-ha⁻¹) were applied by drip irrigation. Dazomet (450 kg-ha⁻¹) was surface applied and soil incorporated. Pebulate (4.5 kg-ha⁻¹) was soil incorporated with some treatments. Pic and 1,3-D + Pic treatments provided good to moderate control of nematodes and soil fungi except in one of the six studies, in which nematode control with 1,3-D was moderate to poor. Nutsedge densities were suppressed by addition of pebulate. Tomato fruit yields with 1,3-D + Pic + pebulate and with Pic + pebulate at the three sites ranged from 85% to 114%, 60% to 95%, and 101% to 119%, respectively, of that obtained with MBR treatments. Pest control and crop yield were lower with treatments other than the above pebulate-containing or MBR-containing treatments. These studies indicate that no one alternative pesticide can provide the consistent broad-spectrum control provided by MBR. Chemical names used: trichloronitromethane (chloropicrin); 1,3-dichloropropene (1,3-D); sodium N-methyldithiocarbamate (metam-sodium); sodium tetrathiocarbonate (tetrathiocarbonate); 3,5-dimethyl-(2H)-tetrahydro-1,3,5-thiadiazine-2-thione (dazomet); isopropyl butyl(ethyl)thiocarbamate (pebulate).

Tomato and bell pepper (*Capsicum annuum* L.) are the two most valuable vegetables grown or fresh-market production in Florida (Geuder and Pugh, 1996). During the 1994-95 crop season, tomato was grown on 19,845 ha and had an on-farm value of \$461 million, and

pepper was grown on 8,200 ha with a value of \$189 million. These two crops accounted for 44% of the monetary value of the vegetable industry in Florida with an average value of \$23,200/ha.

Tomatoes require intense management, including the use of broad-spectrum soil fumigants, polyethylene mulch, and adequate rates of fertilizer, irrigation, and pesticides. Before the use of black polyethylene as a mulch for these crops, most production occurred on new land to avoid or minimize competition from various soil pathogens and weeds. In the early 1970s, most Florida growers were using polyethylene mulch and a broad-spectrum fumigant, which resulted in large increases in yield

over that attained without their use. The fumigants of choice, because of their high efficacy and relatively low cost, are methyl bromide (MBR) and MBR-chloropicrin (Pic) combinations. Typical soils where most vegetables are grown in the southeastern United States have serious soilborne pathogens and pests, including plant-parasitic nematodes, fungi, bacteria, and weeds. Lack of control of any one of these can result in a reduction in yield and quality of fruit. Over the past 25 years, MBR and MBR-Pic combinations became the standard fumigants used with polyethylene-mulched vegetables because they were highly efficacious (Overman and Martin, 1978). Methyl bromide is considered one of the most important preplant soil fumigants available (Noling and Becker, 1994).

In 1992, MBR was alleged to contribute to the depletion of the stratospheric ozone layer (Watson et al., 1992). The U.S. Environmental Protection Agency has established regulations that call for a phaseout of MBR in the United States by 1 Jan. 2001 (U.S. Environmental Protection Agency, 1993). Broad-spectrum control of soilborne pests and pathogens to the degree provided by MBR has not been possible with other currently available fumigants (Methyl Bromide Technical Options Committee, 1995). Chloropicrin is effective against many soilborne diseases but is less effective against nematodes than MBR. The nematicide 1,3-D provides control of nematodes but is not an effective soil fungicide or herbicide. Control of purple and yellow nutsedges (*Cyperus rotundus* L. and *C. esculentus* L.) is not provided by either Pic or 1,3-D (Gilreath et al., 1994); however, these nutsedges must be controlled because both species are very serious weed pests that can easily grow through polyethylene mulch and reduce yields (Locascio et al., 1994).

For economic production of tomato, control of soil pathogens and weeds are essential. With the pending loss of MBR, studies were conducted with polyethylene-mulched tomatoes to evaluate other available preplant fumigants or combinations of chemicals as possible alternatives to MBR.

Materials and Methods

Polyethylene-mulched tomato was grown with drip irrigation at two sites on Millhopper fine sands (Grossarenic Paleudults, loamy, siliceous, hyperthermic) near Gainesville, Fla., during Spring 1994 and 1995, and near Bradenton, Fla., with seep irrigation on an Eau Gallie fine sand (Alfic Haplaquods, sandy, siliceous, hyperthermic) in Spring and Fall 1994. Sites in Gainesville were at the Horticultural Unit and the Green Acres Research Farm. Fields at the Horticultural Unit were heavily infested with purple and yellow nutsedges, and moderately infested with the root-knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood and various soil fungi. The Green Acres site was heavily infested with *Meloidogyne arenaria* (Neal) Chitwood race 1, the peanut root-knot nematode. Sites at Bradenton were heavily infested with purple

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nutsedge, moderately to heavily infested with fusarium wilt (*Fusarium oxysporum* Schlecht. f. sp. *lycopersici* (Sacc.) Snyder and Hans. race 3), and lightly infested with the root-knot nematode *M. incognita*. Treatments included six to 12 fumigants applied during the various seasons with treatments arranged in randomized complete-block designs with six replications. Plots were single rows with 0.9-m-wide bed tops with beds spaced 1.8 m apart and 12 m long at Gainesville and 1.5 m apart and 15.4 m long at Bradenton.

After the initial soil preparation, beds at Gainesville were formed and fertilizer (58N-8P-50K kg-ha⁻¹) was applied in the bed along with the specified soil-applied fumigant and herbicide treatments. Black 0.038-mm-thick polyethylene mulch was then applied over the bed top. Double-wall drip tubing (Chapin Twinwall, Watertown, N.Y.), with emitters spaced 23 cm apart and a flow rate of 62 mL-min⁻¹, was placed 7.5 to 10 cm from the bed center under the mulch for application of water, fertilizer, and fumigants. Postplant fertilizer (144N-130K kg-ha⁻¹ as NH₄NO₃ and KCl) was applied with the irrigation water in 10 weekly applications. At Bradenton, fertilizer (34N-20P-37K kg-ha⁻¹) was applied to the soil and then a prebed was formed. Herbicide and fumigant treatments were applied and a final bed was formed and pressed with fertilizer (247N-284K kg-ha⁻¹) applied in two bands 30 cm from each side of the plant row immediately before application of the polyethylene mulch (black mulch in the spring and white mulch in the fall). Drip tubing identical to that used in Gainesville was placed in appropriate plots 10 cm from the west side of the bed center to allow delivery of drip-applied fumigants. The crop was irrigated with a semi-enclosed, subsurface irrigation system.

Soil fumigants at labeled rates were injected with three chisels per bed spaced 30 cm apart at a depth of 15 to 20 cm. Injected treatments were 98%-2% MBr-Pic (450 kg-ha⁻¹), 67%-33% MBr-Pic (390 kg-ha⁻¹), Pic (390 kg-ha⁻¹), and 1,3-D + 17% Pic (327 L-ha⁻¹). Pebulate (for nutsedge control) was applied on the bed surface and incorporated 15 to 20 cm deep with a roto-tiller before the fumigants were injected. Dazomet (440 kg-ha⁻¹ from a 92% formulation) and metam-sodium (300 L-ha⁻¹ from a 32% formulation) were applied on the bed surfaces and immediately incorporated. At the Horticultural Unit site, dazomet also was incorporated and then watered into the soil with 6 mm depth of water before mulch application. Metam-sodium (300 L-ha⁻¹) and tetrathiocarbonate (1870 L-ha⁻¹) were applied through two drip tubes spaced 30 cm apart per bed at Gainesville, and one drip tube at Bradenton. Tomato was transplanted into the treated soil 3 weeks after fumigant application. Two additional applications of tetrathiocarbonate (187 L-ha⁻¹) were made through the drip irrigation system during the crop growth period at Gainesville and Bradenton.

Tomato plants were set 0.5 m apart in the bed at all sites. 'Sunny' tomato was transplanted in 1994 on 4 Apr. at the Horticultural

Unit and on 6 Apr. at Green Acres. 'AgriSet 761' transplants were set on 28 Mar. 1995 at the Horticultural Unit and on 29 Mar. 1995 at Green Acres. 'Sunbeam' plants were transplanted on 7 Mar. 1994 and 'Sunny' plants were set on 18 Oct. 1994 at Bradenton. Drip irrigation was supplied at 0.75 times pan evaporation throughout both seasons at Gainesville. Subsurface irrigation was continuous at Bradenton to maintain a water table at 46 cm from the bed surface. Tomato plants were pruned by removal of the two lower branches and staked. Foliar insecticides and fungicides were applied weekly beginning 3 weeks after transplanting.

Tomato roots were assessed for the presence of fungi in mid-June of each season at the two Gainesville sites. One typical-appearing, randomly selected tomato plant and root system in each plot was removed from the field. The plants were brought to the laboratory where the soil was washed off the roots. Roots from each plant were excised and placed in an individual container where they were surface-disinfected with a 10% solution (v/v) of bleach (5.25%) for 1 min. Roots were then rinsed twice with sterile distilled water. Three clumps of roots, each weighing 0.25 to 0.35 g, from each plant were placed on acidified potato dextrose agar within each of three petri dishes. Beginning 2 d after plating and up to 9 d after plating, the incidence of all fungi associated with each root clump was assessed. At Bradenton, *Fusarium wilt* race 3 infected plants were enumerated weekly.

After harvest, six plants per plot were collected for assessment of nematode galling of the root system at Gainesville and all of the plants per plot were assessed at Bradenton. A galling index of 0 to 10 was used with 0 = 0 galls, 1 = <10% of roots galled, 2 = 20%, ..., 10 = 100% of the roots galled (Barker et al., 1986).

Counts of emerged nutsedge plants growing through the polyethylene mulch were made 8 weeks after transplanting in an area of 0.095 m². Counts were made on the drip-tubing side of the plots at the Horticultural Unit. At Bradenton, nutsedge plants that emerged through the mulch film were counted in four randomly selected areas on each side of the plant row in each plot and numbers per plot were averaged.

Fruit were harvested twice at the mature green stage and graded into marketable size categories of extra-large, large, and medium fruits by U.S. grade standard (U.S. Dept. of Agriculture, 1976). Data were subjected to analysis of variance with treatment means separated by Duncan's multiple range test (SAS, 1995).

Results and Discussion

Marketable fruit yield. Marketable yields of fruit were influenced by fumigant treatments in all seasons and at all locations (Table 1). Fruit yields were higher than control values and statistically similar among treatments with MBr 98-2, MBr 67-33, Pic + pebulate, and 1,3-D + Pic + pebulate, except at the 1994 Green

Acres site, where the pebulate-containing treatments did not perform as well as the two MBr treatments. During the 1994 fall study at Bradenton, yields with all fumigant treatments were similar and significantly higher than with no fumigant. At the two Gainesville sites, marketable yields varied from intermediate to no higher than the no fumigant treatments with Pic, 1,3-D + Pic, dazomet, dazomet + pebulate, metam-sodium, and metam-sodium + pebulate.

Relative fruit yield with the two MBr treatments was designated as 100% at each site. At the Horticultural Unit site in 1994, relative yields with the Pic + pebulate and with the 1,3-D + Pic + pebulate treatments were 86% and 85%, respectively, and in 1995 they were 114% and 102%, respectively. At Green Acres, relative yields with the two pebulate-containing treatments in 1994 were 60% and 77%, respectively, and in 1995 were both 95%. At Bradenton, relative yields with these two treatments ranged from 101% to 119% during the spring and fall seasons, respectively. In contrast to the fair to excellent production obtained with the two pebulate-containing treatments at the Horticultural Unit in 1994, relative yields were 60% to 70% with Pic, 1,3-D + Pic, dazomet, and metam-sodium drip applied, 45% with soil applied metam-sodium, 47% with tetrathiocarbonate, and 40% with no treatment. Similarly, at Bradenton, yields were reduced with alternative fumigants alone, but where pebulate was combined with fumigants other than metam-sodium in Spring 1994, yields were equal to that with MBr-Pic-containing treatments.

Control of soil fungi. Three predominant pathogenic fungi, *Rhizoctonia solani* Kuhn, *Macrophomina phaseolina* Tassi (Goidanich), and *Fusarium solani* (Mart) Sacc. (emend Snyder and Hans.), were recovered from tomato roots at the two Gainesville sites. Both *R. solani* and *M. phaseolina* are reported as pathogens of tomato (Jones et al., 1991). At Gainesville, the total numbers of colonies of these three fungi isolated from roots were significantly reduced by MBr 98-2 and MBr 67-33 in all studies, by five of six treatments with Pic alone and Pic + pebulate, and by four of seven treatments with 1,3-D + Pic and 1,3-D + Pic + pebulate, as compared with no treatment (Table 2). Dazomet, metam Na, and tetrathiocarbonate treatments did not significantly reduce the number of fungal colonies recovered. Use of Pic alone or in combination with 1,3-D reduced total fungal counts in nine of the 13 treatments. Pic is generally regarded as being more potent than MBr, but in these studies, treatments with MBr (98-2 and 67-33) provided higher consistency for reducing fungal infections than did those with Pic without MBr (2% Pic). At Bradenton (plots were infested with *Fusarium wilt* race 3), use of all fumigants significantly reduced the percentage of plants infected.

Nematode control. At the Horticultural Unit site, root-knot nematode galling indices were significantly lower with soil treatments of MBr 98-2, MBr 67-33, and 1,3-D + Pic alone and + pebulate than with no fumigant treatment (Table 3). Galling indices were interme-

SOIL MANAGEMENT, FERTILIZATION, & IRRIGATION

Table 1. Marketable fruit yield of tomato as influenced by various fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Marketable yield (t·ha ⁻¹) ^a					
		Gainesville				Bradenton	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		20.1 f	20 e	26.5 de	25.9 c	2.2 d	17.4 b
MBR-Pic 98-2%	450 kg	50.5 a ✓	44 ab	48.2 a	47.8 a	49.6 a	— ^c
MBR-Pic 67-33%	390 kg	49.1 a	42 a-c	45.8 a	45.6 a	49.5 a	32.1 a
Chloropicrin (Pic)	390 kg	30.8 c-e ✓	—	34.6 bc	—	26.2 b	—
Pic + pebulate ^b	390 + 4.5 kg	43.0 ab	49 a	28.0 c-e	44.4 ab	—	38.2 a
1,3-D + 17% Pic (C-17)	327 L	34.6 bc	—	33.7 cd	27.4 b	—	—
1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	42.5 ab	44 ab	36.2 b	44.4 ab	50.2 a	34.2 a
Dazomet	440 kg	32.2 cd	—	25.3 e	—	26.9 b	—
Dazomet + 6 mm irrigation	440 kg	30.9 c-e	—	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— ^c	36 cd	—	41.2 a-c	—	30.8 a
Metam Na	300 L	22.6 ef ✓	—	30.4 c-e	—	9.3 cd	—
Metam Na + pebulate	300 L + 4.5 kg	—	33 d	—	34.5 cd	23.9 bc	32.3 a
Metam Na (drip)	300 L	32.3 cd ✓	—	29.8 c-e	—	23.1 bc	—
Tetrathiocarbonate (drip)	1870 L	23.7 ef	—	23.8 e	—	3.6 d	—

^aMarketable fruit included size categories with mean mass of extra-large 205 g, large 150 g, and medium 115 g.^bMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.^cTreatment not applied.^dPic applied at 375 kg in 1995 at Green Acres.

Table 2. Total fungi infecting tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Gainesville (total fungal colonies/plant sample) ^a				Bradenton (<i>Fusarium</i> wilt, % plants infected) ^b	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		11.3 a*	14.3 a	8.0 a	15.5 a	40 a	23 a
MBR-Pic 98-2%	450 kg	3.3 d	4.3 c	2.0 b	8.0 bc	0 c	— ^c
MBR-Pic 67-33%	390 kg	4.8 cd	4.3 c	2.3 b	3.0 c	0 c	0 b
Chloropicrin (Pic)	390 kg	4.3 cd	—	4.3 ab	—	4 c	—
Pic + pebulate ^b	390 + 4.5 kg	4.5 cd	4.3 c	3.0 b	4.0 bc	—	0 b
1,3-D + 17% Pic	327 L	5.0 b-d	—	5.3 ab	8 bc	—	—
1,3-D + 17% Pic + pebulate	327 L + 4.5 kg	2.8 d	3.8 c	4.0 ab	3.5 c	4 c	0 b
Dazomet	440 kg	10.0 ab	—	2.7 b	—	4 c	—
Dazomet + 6 mm irrigation	440 kg	10.3 a	—	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— ^c	8.7 a-c	—	7.0 bc	—	0 b
Metam Na	300 L	11.3 a	—	4.0 ab	—	8 bc	—
Metam Na + pebulate	300 L + 4.5 kg	—	6.8 c	—	3.3 c	4 bc	0 b
Metam Na (drip)	300 L	6.5 a-d	—	3.3 b	—	20 b	—
Tetrathiocarbonate (drip)	1870 L	8.8 a-c	—	8.0 a	—	12 bc	—

^aTotal fungi infecting tomato roots included *Rhizoctonia solani*, *Macrophomina phaseolina*, and *Fusarium* spp.^bPlants infected with *Fusarium oxysporum* f. sp. *lycopersici*.^cMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.^dTreatment not applied.^ePic applied at 375 kg in 1995 at Green Acres.

Table 3. Nematode gall rating of tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nematode gall index ^a				Bradenton Spring 1994
		Gainesville		Green Acres		
		Horticultural Unit		Green Acres		
		1994	1995	1994	1995	
Nontreated	4.5 a [*]	5.3 a	8.9 ab	8.9 a	2.8 ab	
MBR-Pic 98-2%	450 kg	1.0 b	0.2 c	4.1 e	1.1 c	0.2 b
MBR-Pic 67-33%	390 kg	1.2 b	0.4 c	3.6 e	1.4 c	0.2 b
Chloropicrin (Pic)	390 kg	4.3 a	— ^c	8.5 ab	—	0.2 b
Pic + pebulate ^b	390 + 4.5 kg	3.5 a	0.9 c	8.7 ab	5.8 b	—
1,3-D + 17% Pic	327 L	1.2 b	—	6.3 cd	0.2 b	
1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	1.0 b	0.5 c	6.6 cd	2.6 c	0.8 b
Dazomet	440 kg	3.2 ab	—	7.4 bc	—	2.0 ab
Dazomet + 6 mm irrigation	440 kg	3.9 a	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— ^c	2.1 bc	—	3.5 c	—
Metam Na	300 L	3.2 ab	—	9.0 ab	—	4.4 a
Metam Na + pebulate	300 L + 4.5 kg	—	3.9 b	—	7.9 b	2.2 ab
Metam Na (drip)	300 L	3.8 a	—	4.9 de	—	2.8 ab
Tetrathiocarbonate (drip)	1870 L	4.2 a	—	9.7 a	—	3.4 ab

^aRoot-knot gall indices 0–10 with 0 = no galls, ..., 10 = 100% of root system galled.^bMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.^cTreatment not applied.^dPic applied at 375 kg in 1995 at Green Acres.

diate with dazomet + pebulate, and with metam-sodium + pebulate, but were significantly lower than with no fumigant treatment. In 1994, Pic and Pic + pebulate had no significant effect on galling index. At Green Acres in both seasons, root-knot nematode galling indices were reduced most consistently with MBr treatments. Moderate nematode control was provided with 1,3-D + Pic alone or with added pebulate and with metam Na (drip applied) in 1994. Nematode control was similar to that with the no fumigant treatment with Pic, Pic + pebulate, dazomet, metam Na, and tetrathiocarbonate. At Bradenton, nematode counts were low even with the nonfumigated treatments, and root galling indices were not significantly affected by treatment.

Nutsedge control. Nutsedge was a major weed pest at the Horticultural Unit in Gainesville and at the Bradenton site where densities were heavy and very heavy, respectively. At Gainesville, counts of emerged nutsedge seedlings were made ~8 weeks after transplanting tomato (Table 4). Nutsedge population densities were higher on the drip tubing side of the bed than on the opposite and drier side of the bed (data not shown). Nutsedge counts with no treatment on the tubing side of the bed near the end of the two seasons were 30 and 16 plants per 0.1 m², respectively (Table 4). Nutsedge counts during 1994 were low (number in parenthesis) per 0.1-m² area with MBr 98-2 (7), MBr 67-33 (9), Pic + pebulate (11), and with 1,3-D + Pic + pebulate (15). Counts were higher with Pic (22) and 1,3-D + Pic (34). Nutsedge control was poor with the other treatments and emerged numbers were similar to those obtained with no treatment. During the 1995 season, nutsedge counts per m² averaged 3 with the two MBr treatments, 4.5 with the pebulate-containing treatments, and 16 with no treatment. During the Spring 1994 study at Bradenton, the combination of 1,3-D + Pic + pebulate and metam-sodium + pebulate provided nutsedge control as good as that obtained with either MBr 98-2 or MBr 67-33. Nutsedge control with other treatments was poor. In the Fall 1994 study, the combination of pebulate with each of the alternative fumigants provided nutsedge control equal to that obtained with the MBr treatments.

Marketable fruit yield correlated negatively with nutsedge number, root-knot nematode galling indices, and total fungal colonies in roots. In these studies, two treatments, Pic + pebulate, and 1,3-D + Pic + pebulate, suppressed nutsedge, nematode galling, and total fungi comparable to the suppression provided by the standard MBr treatments in most studies.

Data from these studies indicate that multiple pests adversely affect tomato production and that the initial level of these pests influences the degree of control obtained by the

Table 4. Nutsedge growing through polyethylene mulch on tomato beds as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nutsedge (plants/0.1 m ²)			
		Gainesville		Bradenton	
		Horticultural Unit		Spring	Fall
		1994	1995	1994	1994
1 Nontreated		30 a-c	16 a*	53 ab	22 a
2 MBr-Pic 98-2%	450 kg	7 c ✓	2 c	8 d ✓	—
3 MBr-Pic 67-33%	390 kg	9 c ✓	4 c	4 d	1 b
4 Chloropicrin (Pic)	390 kg	22 b-d x	—	60 ab x	—
5 Pic + pebulate*	390 + 4.5 kg	11 c	2 c	—	6 b
6 1,3-D + 17% Pic	327 L	34 a x	—	66 a x	—
7 1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	15 de	3 c	5 d	7 b
8 Dazomet	440 kg	31 ab	—	37 c	—
9 Dazomet + 6 mm irr.	440 kg	25 a-c	—	—	—
10 Dazomet + pebulate	440 + 4.5 kg	—	3 c	—	6 b
11 Metam Na	300 L	32 a x	—	56 ab x	—
12 Metam Na + pebulate	300 L + 4.5 kg	—	10 b	7 d	5 b
13 Metam Na (drip)	300 L	22 cd x	—	51 b x	—
14 Tetrathiocarbonate (drip)	1870 L	33 a	—	54 ab	—

*Mean separation by Duncan's multiple range test, $P \leq 0.05$

*Treatment not applied.

*Pic applied at 375 kg in 1995 at Green Acres.

fumigants. Although no one pesticide provided the broad-spectrum and consistent control provided by MBr, a combination of chemicals did provide similar control in some studies. Pest control and fruit yields were lower with dazomet, metam Na, and tetrathiocarbonate treatments than with the MBr treatments. Where high populations of nutsedge were present, pebulate provided partial control of this weed and, when combined with 1,3-D + Pic or Pic, resulted in sufficient plant growth to obtain 85% to 100% of the yield produced with MBr. In studies where nematodes and fungi populations were high and not adequately controlled, relative yields with Pic + pebulate and with 1,3-D + Pic + pebulate were as low as 60% of that produced with the MBr treatments. With the high cost to produce tomato, this level of yield would not be adequate for long-term sustainable production. For these alternative fumigants to be acceptable, factors that influence the inconsistent control of nematodes and soil fungi at some sites must be determined. Later work at Green Acres indicated that nematode control with 1,3-D + Pic was enhanced by deeper injections to 20 to 30 cm (data not shown) as compared to the 20-cm depth used in the present study. Additional studies on the influence of fumigant rate and placement should provide enhanced control of these pests.

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For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: chloropicrin

[Insert Alternative]

Fumigant alternatives to methyl
Study: bromide for polyethylene-mulched
[Insert Study Title] tomato

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted

X

1b. Township caps

1c. Alternative not acceptable in consuming country

1d. Other (Please describe)

Can be used on tomato, pepper and cucurbit crops.

For EPA Use Only
ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes _____ No _____
1a. If not on the EPA website, please attach a copy.
2. Author(s) or researcher(s) Locascio, Gilreath, Dickson, Kucharek, Jones
and Noling
3. Publication and Date of Publication HortScience, 1997
4. Location of research study Florida
5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
chloropicrin
6. Was crop yield measured in the study? Yes X No _____ tomato yield
7. Describe the effectiveness of the alternative in controlling pests in the study.
Chloropicrin did not control yellow and purple nutsedge.
8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?
We would expect similar results. Our growers would not be able to use this
alternative because of its lack of effectiveness in controlling the pest.
Expected results similar across crops for this pest.

Research Summary Table

Alternative: ChloropirrinStudy: Locascio, Gilreath, Dickson, Kucharek, Jones and Noling, 1997

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us to compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number List the treatment number from the research study you are citing.

Col. B: Treatment List what type of pest control method was used.

Col. C: Rate Enter the pounds or gallons of a chemical used, days of solarization, etc.

Col. D, F, H, J, L, N: Interval Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).

Cols. E, G, I, K, M, O: Rating for Interval: Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.

Control of Pests 1 and 2 (Cols. D - I and Cols. J - O): For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).

Col. J: Yield Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (Gainesville)						Pest 2: Nutsedge (Bradenton)						Tomato Yield (tons/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		8 WAT	30					8 WAT	53					20.1 2.2
2	98/2 methyl bromide + chloropirrin	450 kg/ha	8 WAT	7					8 WAT	8					50.5 49.6
3	67/33 methyl bromide + chloropirrin	390 kg/ha	8 WAT	9					8 WAT	4					49.1 49.5
4	chloropirrin	390 kg/ha	8 WAT	22					8 WAT	60					30.8 26.2

Comments: Nutsedge density was plants per 0.1 m²; nutsedge = yellow and purple; 8 WAT = 8 weeks after treatment; Yield data = Gainesville | Bradenton, Florida).

0.5 - 0.041

If a consortium is submitting this application, the data for this table should reflect a representative user.	
Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per acre in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Acre in 2001 Dollars	Enter the cost per acre in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per acre is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (all) In Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Applications per Year	Cost per Acre (2001\$)
				lbs. ai per Acre per Application	Units of product per Acre per Application	Product Unit (e.g., lbs., gals)						
chloropicrin	nuisance	chloropicrin		347	acres	lb.	\$ 2.50	\$ 75.00	80	100	1	\$ 1,022.50
Non-Chemical Pest Control	Target Pests	Description										Cost/Acre
											Total	\$ 1,022.50

Comments:

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 pounds)	996.69 (Gainesville)	\$ 6.50	\$ 6,478.49
			847.83 (Bradenton)	\$ 6.50	\$ 5,510.90
					\$ 11,989.39
				Total Revenue	\$ 5,994.69

Comments:

worksneet 3-D. Alternatives - Changes in Other Costs for Alternative:

Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No changes

Fumigant Alternatives to Methyl Bromide for Polyethylene-mulched Tomato

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Additional index words. *Lycopersicon esculentum*, chloropicrin, 1,3-dichloropropene, metam-sodium, dazomet, tetrathiocarbonate, pest control, nematodes, fungi, weed control

Abstract. Tomato (*Lycopersicon esculentum* Mill.) was grown to evaluate various chemicals as possible alternatives to methyl bromide soil fumigation. Due to a combination of weeds, nematodes, and soil fungi, the use of a broad-spectrum fumigant has been essential for economical tomato production in Florida. Methyl bromide (MBR) and combinations of MBR with chloropicrin (Pic) are the fumigants of choice for most growers using polyethylene mulch culture. In 1991, MBR was allegedly associated with stratospheric ozone depletion. The U.S. Environmental Protection Agency has since mandated a phaseout of MBR for soil fumigation in the United States by the year 2001. At three locations in Florida, alternative soil fumigants were evaluated, including soil injected 98% MBR-2% Pic at 450 kg-ha⁻¹, 67% MBR-33% Pic (390 kg-ha⁻¹), Pic (390 kg-ha⁻¹), dichloropropene + 17% Pic 1,3-D + Pic at 327 L-ha⁻¹, and metam-sodium (935 L-ha⁻¹). Also, metam-sodium and tetrathiocarbonate (1870 L-ha⁻¹) were applied by drip irrigation. Dazomet (450 kg-ha⁻¹) was surface applied and soil incorporated. Pebulate (4.5 kg-ha⁻¹) was soil incorporated with some treatments. Pic and 1,3-D + Pic treatments provided good to moderate control of nematodes and soil fungi except in one of the six studies, in which nematode control with 1,3-D was moderate to poor. Nutsedge densities were suppressed by addition of pebulate. Tomato fruit yields with 1,3-D + Pic + pebulate and with Pic + pebulate at the three sites ranged from 85% to 114%, 60% to 95%, and 101% to 119%, respectively, of that obtained with MBR treatments. Pest control and crop yield were lower with treatments other than the above pebulate-containing or MBR-containing treatments. These studies indicate that no one alternative pesticide can provide the consistent broad-spectrum control provided by MBR. Chemical names used: trichloronitromethane (chloropicrin); 1,3-dichloropropene (1,3-D); sodium N-methyldithiocarbamate (metam-sodium); sodium tetrathiocarbonate (tetrathiocarbonate); 3,5-dimethyl-(2H)-tetrahydro-1,3,5-thiadiazine-2-thione (dazomet); -propyl butyl(ethyl)thiocarbamate (pebulate).

Tomato and bell pepper (*Capsicum annuum*) are the two most valuable vegetables grown in fresh-market production in Florida (Geuder and Pugh, 1996). During the 1994-95 crop season, tomato was grown on 19,845 ha and had an on-farm value of \$461 million, and

pepper was grown on 8,200 ha with a value of \$189 million. These two crops accounted for 44% of the monetary value of the vegetable industry in Florida with an average value of \$23,200/ha.

Tomatoes require intense management, including the use of broad-spectrum soil fumigants, polyethylene mulch, and adequate rates of fertilizer, irrigation, and pesticides. Before the use of black polyethylene as a mulch for these crops, most production occurred on new land to avoid or minimize competition from various soil pathogens and weeds. In the early 1970s, most Florida growers were using polyethylene mulch and a broad-spectrum fumigant, which resulted in large increases in yield

over that attained without their use. The fumigants of choice, because of their high efficacy and relatively low cost, are methyl bromide (MBR) and MBR-chloropicrin (Pic) combinations. Typical soils where most vegetables are grown in the southeastern United States have serious soilborne pathogens and pests, including plant-parasitic nematodes, fungi, bacteria, and weeds. Lack of control of any one of these can result in a reduction in yield and quality of fruit. Over the past 25 years, MBR and MBR-Pic combinations became the standard fumigants used with polyethylene-mulched vegetables because they were highly efficacious (Overman and Martin, 1978). Methyl bromide is considered one of the most important pre-plant soil fumigants available (Noling and Becker, 1994).

In 1992, MBR was alleged to contribute to the depletion of the stratospheric ozone layer (Watson et al., 1992). The U.S. Environmental Protection Agency has established regulations that call for a phaseout of MBR in the United States by 1 Jan. 2001 (U.S. Environmental Protection Agency, 1993). Broad-spectrum control of soilborne pests and pathogens to the degree provided by MBR has not been possible with other currently available fumigants (Methyl Bromide Technical Options Committee, 1995). Chloropicrin is effective against many soilborne diseases but is less effective against nematodes than MBR. The nematicide 1,3-D provides control of nematodes but is not an effective soil fungicide or herbicide. Control of purple and yellow nutsedges (*Cyperus rotundus* L. and *C. esculentus* L.) is not provided by either Pic or 1,3-D (Gilreath et al., 1994); however, these nutsedges must be controlled because both species are very serious weed pests that can easily grow through polyethylene mulch and reduce yields (Locascio et al., 1994).

For economic production of tomato, control of soil pathogens and weeds are essential. With the pending loss of MBR, studies were conducted with polyethylene-mulched tomatoes to evaluate other available preplant fumigants or combinations of chemicals as possible alternatives to MBR.

Materials and Methods

Polyethylene-mulched tomato was grown with drip irrigation at two sites on Millhopper fine sands (Grossarenic Paleudults, loamy, siliceous, hyperthermic) near Gainesville, Fla., during Spring 1994 and 1995, and near Bradenton, Fla., with seep irrigation on an Eau Gallie fine sand (Alfic Haplaquods, sandy, siliceous, hyperthermic) in Spring and Fall 1994. Sites in Gainesville were at the Horticultural Unit and the Green Acres Research Farm. Fields at the Horticultural Unit were heavily infested with purple and yellow nutsedges, and moderately infested with the root-knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood and various soil fungi. The Green Acres site was heavily infested with *Meloidogyne arenaria* (Neal) Chitwood race 1, the peanut root-knot nematode. Sites at Bradenton were heavily infested with

nutsedge, moderately to heavily infested with fusarium wilt (*Fusarium oxysporum* Schlecht. f. sp. *lycopersici* (Sacc.) Snyder and Hans. race 3), and lightly infested with the root-knot nematode *M. incognita*. Treatments included six to 12 fumigants applied during the various seasons with treatments arranged in randomized complete-block designs with six replications. Plots were single rows with 0.9-m-wide bed tops with beds spaced 1.8 m apart and 12 m long at Gainesville and 1.5 m apart and 15.4 m long at Bradenton.

After the initial soil preparation, beds at Gainesville were formed and fertilizer (58N-8P-50K kg-ha⁻¹) was applied in the bed along with the specified soil-applied fumigant and herbicide treatments. Black 0.038-mm-thick polyethylene mulch was then applied over the bed top. Double-wall drip tubing (Chapin Twinwall, Watertown, N.Y.), with emitters spaced 23 cm apart and a flow rate of 62 mL-min⁻¹, was placed 7.5 to 10 cm from the bed center under the mulch for application of water, fertilizer, and fumigants. Postplant fertilizer (144N-130K kg-ha⁻¹ as NH₄NO₃ and KCl) was applied with the irrigation water in 10 weekly applications. At Bradenton, fertilizer (34N-20P-37K kg-ha⁻¹) was applied to the soil and then a prebed was formed. Herbicide and fumigant treatments were applied and a final bed was formed and pressed with fertilizer (247N-284K kg-ha⁻¹) applied in two bands 30 cm from each side of the plant row immediately before application of the polyethylene mulch (black mulch in the spring and white mulch in the fall). Drip tubing identical to that used in Gainesville was placed in appropriate plots 10 cm from the west side of the bed center to allow delivery of drip-applied fumigants. The crop was irrigated with a semi-enclosed, subsurface irrigation system.

Soil fumigants at labeled rates were injected with three chisels per bed spaced 30 cm apart at a depth of 15 to 20 cm. Injected treatments were 98-2 MBr-Pic (450 kg-ha⁻¹), 67-33 MBr-Pic (390 kg-ha⁻¹), Pic (390 kg-ha⁻¹), and 1,3-D + 17% Pic (327 L-ha⁻¹). Pebulate (for nutsedge control) was applied on the bed surface and incorporated 15 to 20 cm deep with a roto-tiller before the fumigants were injected. Dazomet (440 kg-ha⁻¹ from a 92% formulation) and metam-sodium (300 L-ha⁻¹ from a 32% formulation) were applied on the bed surfaces and immediately incorporated. At the Horticultural Unit site, dazomet also was incorporated and then watered into the soil with 6 mm depth of water before mulch application. Metam-sodium (300 L-ha⁻¹) and tetrathiocarbonate (1870 L-ha⁻¹) were applied through two drip tubes spaced 30 cm apart per bed at Gainesville, and one drip tube at Bradenton. Tomato was transplanted into the treated soil 3 weeks after fumigant application. Two additional applications of tetrathiocarbonate (187 L-ha⁻¹) were made through the drip irrigation system during the crop growth period at Gainesville and Bradenton.

Tomato plants were set 0.5 m apart in the bed at all sites. 'Sunny' tomato was transplanted in 1994 on 4 Apr. at the Horticultural

Unit and on 6 Apr. at Green Acres. 'AgriSet 761' transplants were set on 28 Mar. 1995 at the Horticultural Unit and on 29 Mar. 1995 at Green Acres. 'Sunbeam' plants were transplanted on 7 Mar. 1994 and 'Sunny' plants were set on 18 Oct. 1994 at Bradenton. Drip irrigation was supplied at 0.75 times pan evaporation throughout both seasons at Gainesville. Subsurface irrigation was continuous at Bradenton to maintain a water table at 46 cm from the bed surface. Tomato plants were pruned by removal of the two lower branches and staked. Foliar insecticides and fungicides were applied weekly beginning 3 weeks after transplanting.

Tomato roots were assessed for the presence of fungi in mid-June of each season at the two Gainesville sites. One typical-appearing, randomly selected tomato plant and root system in each plot was removed from the field. The plants were brought to the laboratory where the soil was washed off the roots. Roots from each plant were excised and placed in an individual container where they were surface-disinfected with a 10% solution (v/v) of bleach (5.25%) for 1 min. Roots were then rinsed twice with sterile distilled water. Three clumps of roots, each weighing 0.25 to 0.35 g, from each plant were placed on acidified potato dextrose agar within each of three petri dishes. Beginning 2 d after plating and up to 9 d after plating, the incidence of all fungi associated with each root clump was assessed. At Bradenton, *Fusarium* wilt race 3 infected plants were enumerated weekly.

After harvest, six plants per plot were collected for assessment of nematode galling of the root system at Gainesville and all of the plants per plot were assessed at Bradenton. A galling index of 0 to 10 was used with 0 = 0 galls, 1 = <10% of roots galled, 2 = 20%, ..., 10 = 100% of the roots galled (Barker et al., 1986).

Counts of emerged nutsedge plants growing through the polyethylene mulch were made 8 weeks after transplanting in an area of 0.095 m². Counts were made on the drip-tubing side of the plots at the Horticultural Unit. At Bradenton, nutsedge plants that emerged through the mulch film were counted in four randomly selected areas on each side of the plant row in each plot and numbers per plot were averaged.

Fruit were harvested twice at the mature green stage and graded into marketable size categories of extra-large, large, and medium fruits by U.S. grade standard (U.S. Dept. of Agriculture, 1976). Data were subjected to analysis of variance with treatment means separated by Duncan's multiple range test (SAS, 1995).

Results and Discussion

Marketable fruit yield. Marketable yields of fruit were influenced by fumigant treatments in all seasons and at all locations (Table 1). Fruit yields were higher than control values and statistically similar among treatments with MBr 98-2, MBr 67-33, Pic + pebulate, and 1,3-D + Pic + pebulate, except at the 1994 Green

Acres site, where the pebulate-containing treatments did not perform as well as the two MBr treatments. During the 1994 fall study at Bradenton, yields with all fumigant treatments were similar and significantly higher than with no fumigant. At the two Gainesville sites, marketable yields varied from intermediate to no higher than the no fumigant treatments with Pic, 1,3-D + Pic, dazomet, dazomet + pebulate, metam-sodium, and metam-sodium + pebulate.

Relative fruit yield with the two MBr treatments was designated as 100% at each site. At the Horticultural Unit site in 1994, relative yields with the Pic + pebulate and with the 1,3-D + Pic + pebulate treatments were 86% and 85%, respectively, and in 1995 they were 114% and 102%, respectively. At Green Acres, relative yields with the two pebulate-containing treatments in 1994 were 60% and 77%, respectively, and in 1995 were both 95%. At Bradenton, relative yields with these two treatments ranged from 101% to 119% during the spring and fall seasons, respectively. In contrast to the fair to excellent production obtained with the two pebulate-containing treatments at the Horticultural Unit in 1994, relative yields were 60% to 70% with Pic, 1,3-D + Pic, dazomet, and metam-sodium drip applied, 45% with soil applied metam-sodium, 47% with tetrathiocarbonate, and 40% with no treatment. Similarly, at Bradenton, yields were reduced with alternative fumigants alone, but where pebulate was combined with fumigants other than metam-sodium in Spring 1994, yields were equal to that with MBr-Pic-containing treatments.

Control of soil fungi. Three predominant pathogenic fungi, *Rhizoctonia solani* Kuhn, *Macrophomina phaseolina* Tassi (Goidanich), and *Fusarium solani* (Mart) Sacc. (emend Snyder and Hans.), were recovered from tomato roots at the two Gainesville sites. Both *R. solani* and *M. phaseolina* are reported as pathogens of tomato (Jones et al., 1991). At Gainesville, the total numbers of colonies of these three fungi isolated from roots were significantly reduced by MBr 98-2 and MBr 67-33 in all studies, by five of six treatments with Pic alone and Pic + pebulate, and by four of seven treatments with 1,3-D + Pic and 1,3-D + Pic + pebulate, as compared with no treatment (Table 2). Dazomet, metam Na, and tetrathiocarbonate treatments did not significantly reduce the number of fungal colonies recovered. Use of Pic alone or in combination with 1,3-D reduced total fungal counts in nine of the 13 treatments. Pic is generally regarded as being more potent than MBr, but in these studies, treatments with MBr (98-2 and 67-33) provided higher consistency for reducing fungal infections than did those with Pic without MBr (2% Pic). At Bradenton (plots were infested with *Fusarium* wilt race 3), use of all fumigants significantly reduced the percentage of plants infected.

Nematode control. At the Horticultural Unit site, root-knot nematode galling indices were significantly lower with soil treatments of MBr 98-2, MBr 67-33, and 1,3-D + Pic alone and + pebulate than with no fumigant treatment (Table 3). Galling indices were interme-

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Table 1. Marketable fruit yield of tomato as influenced by various fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Marketable yield (t·ha ⁻¹) ^a					
		Gainesville				Bradenton	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		20.1 f	20 e	26.5 de	25.9 e	2.2 d	17.4 b
MBr-Pic 98-2%	450 kg	50.5 a ✓	44 ab	48.2 a	47.8 a	49.6 a	---
MBr-Pic 67-33%	390 kg	49.1 a	42 a-c	45.8 a	45.6 a	49.5 a	32.1 a
Chloropicrin (Pic)	390 kg	30.8 c-e ✓	---	34.6 bc	---	26.2 b	---
Pic + pebulate*	390 + 4.5 kg	43.0 ab	49 a	28.0 c-e	44.4 ab	---	38.2 a
1,3-D + 17% Pic (C-17)	327 L	34.6 bc	---	33.7 cd	27.4 b	---	---
1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	42.5 ab	44 ab	36.2 b	44.4 ab	50.2 a	34.2 a
Dazomet	440 kg	32.2 cd	---	25.3 e	---	26.9 b	---
Dazomet + 6 mm irrigation	440 kg	30.9 c-e	---	---	---	---	---
Dazomet + pebulate	440 + 4.5 kg	---	36 cd	---	41.2 a-c	---	30.8 a
Metam Na	300 L	22.6 ef ✓	---	30.4 c-e	---	9.3 cd	---
Metam Na + pebulate	300 L + 4.5 kg	---	33 d	---	34.5 cd	23.9 bc	32.3 a
Metam Na (drip)	300 L	32.3 cd ✓	---	29.8 c-e	---	23.1 bc	---
Tetrathiocarbonate (drip)	1870 L	23.7 ef	---	23.8 e	---	3.6 d	---

^aMarketable fruit included size categories with mean mass of extra-large 205 g, large 150 g, and medium 115 g.

^bMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^cTreatment not applied.

^dPic applied at 375 kg in 1995 at Green Acres.

Table 2. Total fungi infecting tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Gainesville (total fungal colonies/plant sample) ^a				Bradenton (<i>Fusarium wilt</i> , % plants infected) ^b	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		11.3 a ^c	14.3 a	8.0 a	15.5 a	40 a	23 a
MBr-Pic 98-2%	450 kg	3.3 d	4.3 c	2.0 b	8.0 bc	0 c	---
MBr-Pic 67-33%	390 kg	4.8 cd	4.3 c	2.3 b	3.0 c	0 c	0 b
Chloropicrin (Pic)	390 kg	4.3 cd	---	4.3 ab	---	4 c	---
Pic + pebulate*	390 + 4.5 kg	4.5 cd	4.3 c	3.0 b	4.0 bc	---	0 b
1,3-D + 17% Pic	327 L	5.0 b-d	---	5.3 ab	8 bc	---	---
1,3-D + 17% Pic + pebulate	327 L + 4.5 kg	2.8 d	3.8 c	4.0 ab	3.5 c	4 c	0 b
Dazomet	440 kg	10.0 ab	---	2.7 b	---	4 c	---
Dazomet + 6 mm irrigation	440 kg	10.3 a	---	---	---	---	---
Dazomet + pebulate	440 + 4.5 kg	---	8.7 a-c	---	7.0 bc	---	0 b
Metam Na	300 L	11.3 a	---	4.0 ab	---	8 bc	---
Metam Na + pebulate	300 L + 4.5 kg	---	6.8 c	---	3.3 c	4 bc	0 b
Metam Na (drip)	300 L	6.5 a-d	---	3.3 b	---	20 b	---
Tetrathiocarbonate (drip)	1870 L	8.8 a-c	---	8.0 a	---	12 bc	---

^aTotal fungi infecting tomato roots included *Rhizoctonia solani*, *Macrophomina phaseolina*, and *Fusarium* spp.

^bPlants infected with *Fusarium oxysporum* f. sp. *lycopersici*.

^cMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^dTreatment not applied.

^ePic applied at 375 kg in 1995 at Green Acres.

Table 3. Nematode gall rating of tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nematode gall index ^a				Bradenton Spring 1994
		Gainesville				
		Horticultural Unit		Green Acres		
		1994	1995	1994	1995	
Nontreated	4.5 a ^c	5.3 a	8.9 ab	8.9 a	2.8 ab	
MBr-Pic 98-2%	450 kg	1.0 b	0.2 c	4.1 e	1.1 c	0.2 b
MBr-Pic 67-33%	390 kg	1.2 b	0.4 c	3.6 e	1.4 c	0.2 b
Chloropicrin (Pic)	390 kg	4.3 a	— ^a	8.5 ab	—	0.2 b
Pic + pebulate [*]	390 + 4.5 kg	3.5 a	0.9 c	8.7 ab	5.8 b	—
1,3-D + 17% Pic	327 L	1.2 b	—	6.3 cd	0.2 b	
1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	1.0 b	0.5 c	6.6 cd	2.6 c	0.8 b
Dazomet	440 kg	3.2 ab	—	7.4 bc	—	2.0 ab
Dazomet + 6 mm irrigation	440 kg	3.9 a	—	—	—	—
Dazomet + pebulate	440 + 4.5 kg	— ^a	2.1 bc	—	3.5 c	—
Metam Na	300 L	3.2 ab	—	9.0 ab	—	4.4 a
Metam Na + pebulate	300 L + 4.5 kg	—	3.9 b	—	7.9 b	2.2 ab
Metam Na (drip)	300 L	3.8 a	—	4.9 de	—	2.8 ab
Tetrathiocarbonate (drip)	1870 L	4.2 a	—	9.7 a	—	3.4 ab

Root-knot gall indices 0-10 with 0 = no galls, ---, 10 = 100% of root system galled.

Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^aTreatment not applied.

^bPic applied at 375 kg in 1995 at Green Acres.

diate with dazomet + pebulate, and with metam-sodium + pebulate, but were significantly lower than with no fumigant treatment. In 1994, Pic and Pic + pebulate had no significant effect on galling index. At Green Acres in both seasons, root-knot nematode galling indices were reduced most consistently with MBr treatments. Moderate nematode control was provided with 1,3-D + Pic alone or with added pebulate and with metam Na (drip applied) in 1994. Nematode control was similar to that with the no fumigant treatment with Pic, Pic + pebulate, dazomet, metam Na, and tetrathiocarbonate. At Bradenton, nematode counts were low even with the nonfumigated treatments, and root galling indices were not significantly affected by treatment.

Nutsedge control. Nutsedge was a major weed pest at the Horticultural Unit in Gainesville and at the Bradenton site where densities were heavy and very heavy, respectively. At Gainesville, counts of emerged nutsedge seedlings were made ~8 weeks after transplanting tomato (Table 4). Nutsedge population densities were higher on the drip tubing side of the bed than on the opposite and drier side of the bed (data not shown). Nutsedge counts with no treatment on the tubing side of the bed near the end of the two seasons were 30 and 16 plants per 0.1 m², respectively (Table 4). Nutsedge counts during 1994 were low (number in parenthesis) per 0.1-m² area with MBr 98-2 (7), MBr 67-33 (9), Pic + pebulate (11), and with 1,3-D + Pic + pebulate (15). Counts were higher with Pic (22) and 1,3-D + Pic (34). Nutsedge control was poor with the other treatments and emerged numbers were similar to those obtained with no treatment. During the 1995 season, nutsedge counts per m² averaged 3 with the two MBr treatments, 4.5 with the pebulate-containing treatments, and 16 with no treatment. During the Spring 1994 study at Bradenton, the combination of 1,3-D + Pic + pebulate and metam-sodium + pebulate provided nutsedge control as good as that obtained with either MBr 98-2 or MBr 67-33. Nutsedge control with other treatments was poor. In the Fall 1994 study, the combination of pebulate with each of the alternative fumigants provided nutsedge control equal to that obtained with the MBr treatments.

Marketable fruit yield correlated negatively with nutsedge number, root-knot nematode galling indices, and total fungal colonies in roots. In these studies, two treatments, Pic + pebulate, and 1,3-D + Pic + pebulate, suppressed nutsedge, nematode galling, and total fungi comparable to the suppression provided by the standard MBr treatments in most studies.

Data from these studies indicate that multiple pests adversely affect tomato production and that the initial level of these pests influences the degree of control obtained by the

Table 4. Nutsedge growing through polyethylene mulch on tomato beds as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nutsedge (plants/0.1 m ²)			
		Gainesville		Bradenton	
		Horticultural Unit		Spring	Fall
		1994	1995	1994	1994
1 Nontreated		30 a-c	16 a*	53 ab	22 a
2 MBr-Pic 98-2%	450 kg	7 e ✓	2 c	8 d	—
3 MBr-Pic 67-33%	390 kg	9 e ✓	4 c	4 d	1 b
4 Chloropicrin (Pic)	390 kg	22 b-d x	—	60 ab x	—
5 Pic + pebulate	390 + 4.5 kg	11 e	2 c	—	6 b
6 1,3-D + 17% Pic	327 L	34 a x	—	66 a x	—
7 1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	15 de	3 c	5 d	7 b
8 Dazomet	440 kg	31 ab	—	37 c	—
9 Dazomet + 6 mm irr.	440 kg	25 a-c	—	—	—
10 Dazomet + pebulate	440 + 4.5 kg	—	3 c	—	6 b
11 Metam Na	300 L	32 a x	—	56 ab x	—
12 Metam Na + pebulate	300 L + 4.5 kg	—	10 b	7 d	5 b
13 Metam Na (drip)	300 L	22 cd x	—	51 b x	—
14 Tetrathiocarbonate (drip)	1870 L	33 a	—	54 ab	—

*Mean separation by Duncan's multiple range test, $P \leq 0.05$

x Treatment not applied.

*Pic applied at 375 kg in 1995 at Green Acres.

fumigants. Although no one pesticide provided the broad-spectrum and consistent control provided by MBr, a combination of chemicals did provide similar control in some studies. Pest control and fruit yields were lower with dazomet, metam Na, and tetrathiocarbonate treatments than with the MBr treatments. Where high populations of nutsedge were present, pebulate provided partial control of this weed and, when combined with 1,3-D + Pic or Pic, resulted in sufficient plant growth to obtain 85% to 100% of the yield produced with MBr. In studies where nematodes and fungi populations were high and not adequately controlled, relative yields with Pic + pebulate and with 1,3-D + Pic + pebulate were as low as 60% of that produced with the MBr treatments. With the high cost to produce tomato, this level of yield would not be adequate for long-term sustainable production. For these alternative fumigants to be acceptable, factors that influence the inconsistent control of nematodes and soil fungi at some sites must be determined. Later work at Green Acres indicated that nematode control with 1,3-D + Pic was enhanced by deeper injections to 20 to 30 cm (data not shown) as compared to the 20-cm depth used in the present study. Additional studies on the influence of fumigant rate and placement should provide enhanced control of these pests.

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For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: Metam Na + 1,3-D + Pebulate

[Insert Alternative]

Study: Soil flooding and chemical alternatives to methyl bromide in
[Insert Study Title]. tomato production

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted _____

1b. Township caps _____

1c. Alternative not acceptable in consuming country _____

1d. Other (Please describe) X

Pebulate is not labeled in pepper, strawberry or cucurbit crops.

Metam Na + 1,3-D can be used in tomato, strawberry, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes _____ No _____
 1a. If not on the EPA website, please attach a copy. _____
2. Author(s) or researcher(s) Nelson, Locascio, Allen, Dickson and Mitchell

3. Publication and Date of Publication 1999 Proc. of the Annual International Conf. on Methyl Bromide
4. Location of research study Florida
5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
Metam Na + 1,3-D + pebulate

6. Was crop yield measured in the study? Yes X No _____ tomato yield
7. Describe the effectiveness of the alternative in controlling pests in the study.
The alternative of Metam Na + 1,3-D + pebulate was not effective in controlling yellow and purple nutsedge. Pebulate is registered on tomato but not pepper, cucurbit crops or strawberries. These results show the inconsistency of Metam Na and 1,3-D in controlling nutsedge.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?
Our growers would not use this alternative because of the inconsistency in products and the need for a tractor mounted tillage implement to incorporate this alternative which most growers do not have.

Research Summary Table

Alternative: Metam-Na + 1,3-D + Pebulate

Study: Nelson, Locascio, Allen, Dickson and Mitchell, 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Yellow and Purple Nutsedge						Pest 2						Tomato Yield (tons/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		*	21.8											25.0
2	67/33 methyl bromide + chloropicrin	392 kg/ha	*	1.6											52.0
5	Metam-Na +	300 L	*												
	1,3-D +	112 L													
	pebulate	4.5 kg/ha		12											37.0

Comments: Density of yellow and purple nutsedge per 0.1 m²; * = could not determine from report.

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Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (a) In Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Applications per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
metam-Na +	nutrsedge	metam-Na	4.26	300 L/ha	32	gal	\$ 4.00	\$ 90.00	60	100	1	\$ 289.00
1,3-D +				112 L/ha	11.98	gal	\$ 11.40					\$ 136.57
pebulate				4.5 kg/ha	0.89	gal	\$ 50.00	\$ 15.00		100	1	\$ 59.50
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 494.07

Comments: Hand removal of nutsedge is impossible and would likely cost \$2,000 per acre.

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The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle.

If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.

Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.

Enter the unit of measurement for your crop/commodity.

Enter the number of units of crop/commodity produced per area for that price factor identified.

Enter the average 2001 prices received by the users for that crop/commodity and price factor.

In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments:

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Metam-Na + 1,3-D + Pebulate

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25.00			\$ 15.00	Tractor with tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

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Soil Flooding and Chemical Alternatives to Methyl Bromide in Tomato Production

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Alternative nonchemical and chemical replacements for methyl bromide (MB) are being explored to find an effective chemical or alternative agricultural practice to control vegetable crop pests. One of the most promising chemical alternatives for MB replacement for tomato production has been a combination of 1,3-Dichloropropene with 17% or 35% chloropicrin (Pic) with the herbicide pebulate (S-propyl butyl(ethyl)thiocarbamate). A nonchemical alternative is the use of flooding as a potential method of controlling pests in the mineral and peat soils of Florida. It has been estimated that approximately as much as 20% of Florida soils are or could be flooded periodically during a portion of the year. In past studies, flooding the soil has been shown to reduce nematode populations in peat and some mineral soils and may suppress weed seed viability and disease. The purpose of this study was to evaluate the effectiveness of off-season flooding for control of pests in tomato (*Lycopersicon esculentum* Mill.) production and to compare its effects against pre-plant fumigants in a mineral soil. The effects of flooding and chemical treatments were evaluated for control of plant disease, root-knot nematode (*Meloidogyne incognita* L.), and nutsedge (*Cyperus* spp.).

A field site consisting of Millhopper fine sand (loamy, siliceous, hyperthermic Grossarenic Paleudults) at the Horticultural Research Unit in Gainesville, Florida was selected for a pre-plant soil flooding and chemical treatment study. The field site was divided into eight sections (16 m x 27 m each) for a randomized split plot design arranged with two mainplot treatments, flooding and nonflooding, and each replicated within four blocks. Flooded plots were managed with an flood-drain-flood schedule of 3 weeks flooding, 5 weeks drying, followed by 3 weeks flooding between 16 Nov. 1998 and 29 Jan. 1999. Soil anaerobic conditions in flooded plots were monitored with oxidation-reduction potential probes and aerobic conditions in adjacent nonflooded plots were determined by measuring water table depth in well points placed to a depth of 0.8 m. All plots were rototilled 2 weeks after each flooding event, and caution was taken to not cross contaminate non-flooded plots with flooded plots with rototiller equipment.

Raised bed rows (0.9 m wide x 15 m long) were shaped and centered within mainplots for subplot chemical treatments and buffer rows. Pre-plant chemical treatments applied on 18 Feb. 1999 included 67% MB + 33% Pic at 392 kg ha⁻¹, 1,3-Dichloropropene (1,3-D) with 17% (C-17) and 35% (C-35) Pic at 327 L ha⁻¹ plus 4.5 kg ha⁻¹ pebulate (Peb), metam-sodium at 300 L ha⁻¹ plus 1,3-D at 112 L ha⁻¹ plus 4.5 kg ha⁻¹ Peb, and an untreated (check) row. Metam-sodium (sodium N-methylthiocarbamate) and pebulate were sprayed on the soil surface of designated rows and tilled into the rows. Fumigants were injected under black polyethylene mulch (0.038 mm thick) to a depth of 30 cm with 3 chisels spaced 35 cm apart. Drip irrigation tubing was placed at the center of the bed for irrigation and fertigation. On 24 Mar. 1999 'Florida 47' tomato seedlings were transplanted at a spacing of 0.45 m apart. Nutsedge density was determined with the use of a 0.1-m² template and placed at random on the drip line side of the

weekly for disease, and moribund or dead plants were brought to the
 gens. Tomatoes were harvested three times, 3 June, 15 June, and
 ted into size class categories and weighed. After fruit was
 were dug, and roots were rated for presence of root knot nematodes
 by *Pythium* spp.

check plots were not
 he average values
 ntsedge control as
 bded than the non-
 ed the true potential of
 ut each flooding event.
 pl differences as have

soil conditions within the flooded plots was confirmed by
 decreasing from a well oxygenated system (>400 mV) to a fairly
 otential reading. It took 1-2 weeks before the lowest potential
 tion-reduction potential increased to aerobic soil conditions within
 were drained. Adjacent non-flooded plots were aerobic within the
 emained below a depth 0.3 m in water wells.

rolific in untreated rows and resulted in significantly higher weeds
 ulch than the chemical treatments (Table 1). Metam-Na combined
 ve actually stimulated ntsedge growth causing significantly greater
 fumigant treatments. The 1,3-D plus C-17 or C-35 treatments
 etter ntsedge control as the MB 67-33+Pic treatment. The
 by pebulate in the C-17 and C-35 treatments suggests that applying
 1,3-D may inhibit its herbicidal activity.

were statistically equivalent in MB, C-17, and C-35 treatments,
 r yields than both metam-Na+1,3-D+Peb and untreated treatments
 ato plants in untreated plots, whether flooded or non-flooded prior
 ed, and they were visually lower in height, vigor, and disease
 rows. Control of both nematodes and fungal diseases were
 d than chemically treated subplots, as root-knot galling and root rot
 -fumigated rows (Table 1). The overall equivalent pest control and
 or C-35 treatments as compared with MB reconfirm that these
 e the appropriate replacement for MB in Florida tomato production.
 -Na+1,3D+Peb suggest that this cocktail mixture will not be a
 MB in polyethylene mulch tomato production. Note that the
 ent resulted in nematode and root disease control as good as that of
 This suggests that the decreased yield observed in the metam-
 ost likely due to its poor ability to inhibit ntsedge growth.

ge was observed in the non-flooded control rows and the thick
 / contributed to decreased growth rate and high susceptibility to
 ntsedge species in the flooded control rows confirms that ntsedge
 litions. In fact, during the flooding event ntsedge was observed
 These results suggest that control of ntsedge may have to
 yields similar to that under MB fumigation.

Table 1. Nutsedge density counts, marketable tomato fruit yields, root-knot nematode root-gall ratings, and root-rot disease ratings as influenced by off-season flooding and pre-plant fumigant and herbicide treatments during a Winter 1998 to Spring 1999 study at Gainesville, FL.

Mainplot		Mark. yield (t/ha)			Nutsedge no. per 0.1			Nematode gall index ^x			Root Rot index ^y		
Not Flooded		38.8			6.4			1.9			1.7		
Flooded		34.9			3.1			1.4			1.6		
Significance		NS			NS			NS			NS		
Subplot ^z Treatment	Rate/ha	NF	F	Ave	NF	F	Ave	NF	F	Ave	NF	F	Ave
1 Untreated	0	25c	31c	28c	21.8a	9.5a	15.7	6.4a	4.8a	5.6a	3.0a	2.7a	2.8a
2 MB-Pic 67-33	392 kg	52a	51a	52a	1.6c	1.2c	1.4b	1.0b	1.3b	1.1b	1.5b	1.4bc	1.4b
3 1,3-D+17%Pic+Peb	327 L + 4.5 kg	49a	49ab	49a	1.3c	2.9c	2.1b	1.5b	1.0b	1.2b	1.6b	1.8b	1.7b
4 1,3-D+35%Pic+Peb	327 L + 4.5 kg	47a	47ab	47a	0.7c	0.7c	0.7c	0.8b	2.0b	1.4b	1.4b	1.8b	1.6b
5 Met-Na+1,3-D+Peb	300L+112L+4.5 kg	37b	41bc	39b	12.0 b	3.8b	7.9b	1.0b	0.9b	0.9b	1.6b	1.4bc	1.5b

^zSubplot treatment legend: MB=methyl bromide, Pic=chloropicrin, 1,3-D=1,3 dichloropropene, Peb=pebulate, and met-Na=metam sodium
NF=not flooded, F=Flooded, Ave=Average of NF and F.

^yRoot rot indices of 1-5 with 1=<10% rot, 2=10-25%, 3=25-75%, 4=75-100% of root system diseased, and 5=dead roots.
(root rot was caused predominantly by *Pythium aphanidermatum* or *P. myriotylum*).

^xRoot knot gall indices 0-10 with 0=no galls, 1=1-10%, 2=11-20%, ..., and 10=100% of root system galled.
Mean separation within columns by Duncan's multiple range test, P=0.05

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3-A(6)f

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: metamsodium + dichloropropenet Study: Alternative fumigants for methyl bromide in tobacco & pepper
(Insert Alternative) chloropicrin (Insert Study Title) transplant producti

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X _____

Can be used in pepper, tomato, strawberry and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Csinos, Johnson, Johnson, Sumner, PcPherson
and Gitatitis

3. Publication and Date of Publication Crop Protection, 1997

4. Location of research study Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
metam sodium + 1,3-D, C-17

6. Was crop yield measured in the study? Yes _____ No X

7. Describe the effectiveness of the alternative in controlling pests in the study.

Highest rates of this material gave equivalent control of yellow
nutsedge to methyl bromide. Lowest rates were not effective.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Growers in our area would use reduced rates which would lead to lack of
control of yellow nutsedge. Also, metam sodium was incorporated with a
tractor-powered rototiller which most of our growers do not own. Similar
results would be likely in tomato, strawberry and cucurbit crops.

Research Summary Table

Alternative: Metam-sodium + dichloropropene + chloropicrin

Study: Casnos, Johnson, Johnson, Sumner, McPherson, and Gitaitis, 1997

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. a/ per area)	Pest 1: Yellow Nutsedge (1993-1994)						Pest 2: Yellow Nutsedge (1994-1995)						Yield (units/area)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
8	untreated		148	0					153	0					
1	methyl bromide	489 kg/ha	148	95					153	95					
6	metam-sodium +	468													
	dichloropropene,														
	chloropicrin	126 L/ha	148	86					153	77					
7	metam-sodium +	486 L/ha													
	dichloropropene,														
	chloropicrin	126 L/ha	*	*					153	50					

Comments: * = not included in 1993-1994 study; yield was not determined because study related to transplant production only.

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Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.

Col. 8: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.

Col. C: Active Ingredients	Use one row for each active ingredient (a). For example, if a product contains 2 a's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.

Col. D: Formulation	Enter the formulation or the % of active ingredient.

Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.

Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.

Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.

Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.

Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.

Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

[illegible]

Comments:

Total	\$ 639.50

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If a consortium is submitting this application, the data for this table should reflect a representative user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments: * = estimated value

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Metam-sodium + dichloropropene + chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25.00			\$ 15.00	Tractor with tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

05-0041



Alternative fumigants for methyl bromide in tobacco and pepper transplant production

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Tobacco and pepper are high-value cash crops in the southeastern USA that require vigorous transplants free of pathogens and insects. Typically soil seedbeds are treated with methyl bromide prior to seeding. Soil fumigants metam-sodium, dichloropropene, chloropicrin and dazomet covered with polyethylene film were evaluated at several rates alone and in combination as alternatives for methyl bromide soil fumigation of tobacco and pepper seedbeds. The studies were conducted over a three-year period, with materials applied in the fall prior to seeding at the beginning of the following year. Nematode and insect pressures were low in each of three sites, but the tests extensively evaluated weeds and soilborne fungi management. Metam-sodium at 935 L ha⁻¹ performed well in all three tests. The combination of metam-sodium (468 L ha⁻¹) plus dichloropropene + 17% chloropicrin (126 L ha⁻¹) provided good control of most of the pests and had high plant yield and vigor when covered with a polyethylene film immediately after treatment. A similar treatment not covered with polyethylene film but sealed with a mechanical soil cultipacker provided poor control of weeds. Stunting of tobacco and pepper was noted, especially in plots treated at the highest rates of metam-sodium plus dichloropropene and chloropicrin. These treatments had a pungent odor associated with the treatment, which persisted for several weeks after polyethylene film removal. Many of the treatments, especially metam-sodium and metam-sodium in combination with dichloropropene and chloropicrin, compared well with methyl bromide fumigation for seedbed pest control. © 1997 Elsevier Science Ltd

Keywords: metam-sodium; dichloropropene; chloropicrin; dazomet; pest control

Alternative fumigants for methyl bromide in tobacco and pepper transplant production

Tobacco (*Nicotiana tabacum* L.) is a high-value cash crop in the southeastern USA that requires the production of healthy and vigorous transplants. Weeds, soil arthropods, nematodes, bacteria and fungi can be serious pests or pathogens of seedlings (Todd *et al.*, 1950; Koch, 1951; Todd and Lucas, 1956; Lucas, 1975). Typically, field-grown tobacco seedlings are produced in methyl bromide fumigated soil to manage these pest problems. However, because of implications that methyl bromide is involved in depleting the stratospheric ozone layer, in 1992 the US Environmental Protection Agency initiated action under the Clean Air Act, which mandates a phasing out of all materials threatening the ozone layer by the year 2001 (Noling and Becker, 1994).

Methyl bromide has become the standard as a soil fumigant to manage soil arthropods, weeds, fungi, bacteria and nematodes in tobacco and pepper transplant production (Koch, 1951; Martin *et al.*, 1955; Todd and Lucas, 1956). No other single pesticide is

available that has the broad spectrum of activity against all of these pests. Metam-sodium (sodium N-methyldithiocarbamate) and dazomet (tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione), a granular non-volatile biocide, degrade in the soil to form methylisothiocyanate, which has good activity against nematodes, fungi, insects and weeds (Munneche *et al.*, 1962; Vaartaja, 1964; McCarter *et al.*, 1976a,b; Jaworski *et al.*, 1978; Johnson *et al.*, 1979b). The fumigant 1,3-dichloropropene has high activity against nematodes and some soil arthropods, but poor to fair activity against fungi and weeds (Youngson and Goring, 1962; Noling and Becker, 1994). Chloropicrin (trichloronitromethane) has good activity on insects and fungi but may not be as effective as methyl bromide on weeds and nematodes (Newhall, 1953; Johnson *et al.*, 1979a; Johnson and Feldmesser, 1987).

Other alternatives to methyl bromide fumigation may be the use of non-fumigant nematicides, herbicides, insecticides and fungicides (Brodie *et al.*, 1968; Johnson *et al.*, 1975; Noling and Becker, 1994). However, these specific pesticides alone, in each of

the pest groups, may not have adequate broad spectrum activity to control all of the pests that may be encountered in the soil.

This work was initiated to evaluate the most logical alternatives to methyl bromide fumigation for tobacco seedling production. Pepper (*Capsicum annuum* L.), another transplanted crop produced in plant beds of this study, was included in two of the three years studied.

Since these fumigants have limitations on efficacy, they were used in combinations to maximize the benefits of each product to control the target pests that are controlled by methyl bromide (Table 1).

Materials and methods

General

The research was conducted in field plots on fuquay loamy sand (loamy, siliceous thermic arenic plinthic paleudults) at the Coastal Plain Experiment Station, Tifton, GA, USA. Randomized complete block designs were used with seven treatments and a non-treated control with four replicates in 1992 and six replicates in 1993 and 1994. A different location was selected each year. Each plot was 1.82 m wide and 7.62 m long, and a 1.2–1.82 m wide skip separated plots on the sides. Alleys between replications were 3.8 m wide. Plots were fertilized with

0.5–0.8 kg m⁻² of 6–12–6 (N–P₂O₅–K₂O) plant bed fertilizer prior to treatment. Plots were top-dressed during the season with 16–0–0 as required and water was applied with overhead irrigation as required. Tobacco seedbed management followed the recommendations of the Georgia Cooperative Extension Service (Moore *et al.*, 1993). All plots, unless indicated otherwise, including the non-treated control, were covered with 1 mil polyethylene film immediately after treatment.

1992–93

The plot area had previously been in peanut (1990), peanut (1991) and tobacco (1992) and not been treated with methyl bromide during those crops. Treatments were applied on 10 November 1992 at the following rates: methyl bromide (98% methyl bromide+2% chloropicrin) at 489 kg ha⁻¹; metam-sodium (30%) at 935 L ha⁻¹; dichloropropene at 187 L ha⁻¹; a combination of metam-sodium at 467 L ha⁻¹+dichloropropene+17% chloropicrin at 93 L ha⁻¹; dazomet (98%) at 387 kg ha⁻¹; chloropicrin at 56 L ha⁻¹; and dichloropropene+30% chloropicrin at 187 L ha⁻¹.

Chloropicrin, dichloropropene and methyl bromide were applied through chisels into the soil to a depth of 20 cm prior to covering with 1 mil polyethylene film. Metam-sodium was applied to the soil surface with a sprayer mounted in front of a tractor-powered rototiller, incorporated to a depth of 15–20 cm and covered with polyethylene film. In combination treatments the chiselled chemicals were applied first, the metam-sodium applied next and the rototiller mixed the two materials in the soil prior to covering with polyethylene film. The polyethylene film was removed from all plots on 7 December 1992 to allow aeration. Beds were rototilled and shaped on 25 January 1993 and seeded with a Stanhay seeder on 26 January 1993 at the rate of 63 pelletized 'K-326' tobacco seeds m⁻¹ and 'Pip' bell pepper at the rate of 60 seeds m⁻¹. The row pattern per bed was six rows of tobacco and six rows of pepper. All beds were covered with 3 mil polyethylene film to retain moisture and protect beds from adverse weather immediately after seeding and irrigation. Plant bed maintenance, except pesticide application, followed the recommendations of the Georgia Cooperative Extension Service (Moore *et al.*, 1993).

Preliminary data and results from studies with onions indicated the fumigants tested had little effect on bacterial populations. To evaluate if the presence of bacteria in fumigated soils was from rapid repopulation or inefficacy of the fumigation process, two methods were employed.

First, soil samples were taken from field plots prior to fumigation to establish bacterial populations. After fumigation, samples were taken prior to removal of the plastic film by using aseptic techniques to cut a slit in the plastic and retrieve a soil core (2.5 cm diameter × 15 cm deep). Samples of the 1 g soil were added to 10 ml of buffered saline (0.85% NaCl 0.05 M K₂HPO₄–KH₂PO₄, pH 7.2) and shaken on a

Table 1. Pests evaluated in fumigant tests

Latin binomial	Common name (USA)
Weeds	
<i>Cyperus esculentus</i> L.	Yellow nutsedge
<i>Digitaria sanguinalis</i> (L.) Scop.	Southern crabgrass
<i>Geranium carolinianum</i> L.	Carolina geranium
<i>Gnaphalium purpureum</i> L. var. <i>purpureum</i>	Purple cudweed
<i>Lamium amplexicaule</i> L.	Henbit
<i>Linaria canadensis</i> (L.) Dum.	Old field toadflax
<i>Oenothera laciniosa</i> Hill	Cutleaf evening primrose
<i>Richardia scabra</i> L.	Florida pusley
Fungi	
<i>Aspergillus</i> spp.	
<i>Fusarium oxysporum</i> Schlechtend.:Fr.	
<i>Fusarium solani</i> (Mart.) Sacc.	
<i>Puccinomyces</i> spp.	
<i>Penicillium</i> spp.	
<i>Pythium irregulare</i> Buismann	
<i>Pythium</i> spp.	
<i>Phytophthora parasitica</i> var. <i>nicotianae</i> (Breda de Haan) Tucker	
<i>Rhizoctonia solani</i> Kühn AG-4	
<i>Trichoderma</i> spp.	
Arthropods	
<i>Conoderus</i> spp.	Wireworms
<i>Delia platura</i> Meigen	Seedcorn maggots
<i>Listroderes difficilis</i>	Vegetable weevil
Scarabidae	Grubs
<i>Scotopercus</i> spp.	Mole crickets
Staphylinidae	Love beetles
Nematodes	
<i>Criconemella ornata</i> (Raski) Luc and Raskin	Ring nematode
<i>Meloidogyne</i> spp.	Root knot nematodes
Bacteria	
<i>Clavibacter michiganensis</i> subsp. <i>michiganensis</i> (Smith) Davis, Gillespie, Vidaver and Harris	

rotary shaker for 15 min. Soil suspensions were serially diluted (1:9) to a concentration of 0.0001 of the original suspension. Aliquots of 0.1 ml from each dilution were spread plate on to nutrient agar.

Second, rifampicin-resistant mutants of *Clavibacter michiganensis* subsp. *michiganensis* (Smith) Davis, Gillaspie, Vidavar and Harris were inoculated in tomato stems as previously described (Gitaitis *et al.*, 1991). Stems were collected after six weeks, trimmed to a length of 15 cm, packed in field soil in nylon mesh and buried in field plots at a depth of 10 cm prior to fumigation. Samples were collected and processed as above except aliquots of the dilutions were spread onto plates of D₂anx medium (Dhanvantari 1987) supplemented with 50 µg ml⁻¹ rifampicin. The total number of colony-forming units (cfu) was enumerated on nutrient agar and the total number of *C. michiganensis* subsp. *michiganensis* colony types was enumerated on D₂anx supplemented with rifampicin.

Twenty soil samples were collected as cores (2.5 cm diameter × 15 cm deep) from plots after the polyethylene film was removed. The soil was assayed for populations of *Pythium* spp. (P₅ARP media) (Jeffers and Martin, 1986), *Rhizoctonia solani* Kühn AG-4 (tannic acid-benomyl) (Henis *et al.*, 1978; Sumner *et al.*, 1978; Sumner and Bell, 1982), *Fusarium solani* (Mart.) Sacc. and *Fusarium oxysporum* Schlecht. Fr. (modified PCNB) (Papavizas, 1967), *Aspergillus* spp., *Trichoderma* spp., *Penicillium* spp., *Paecilomyces* spp. (OAES media) (Williams and Schmitthenner, 1960), *Meloidogyne* spp. and other plant parasitic nematodes. Nematodes were extracted from 150 cm³ soil by the centrifuge sugar flotation method (Jenkins, 1964). Toothpicks infested with *Phytophthora parasitica* var. *nicotianae* (Breda de Haan) Tucker were placed in nylon mesh bags and buried in plots at a depth of 2–3 cm at the time of treatment, retrieved when the polyethylene film was removed and bioassayed by inserting the toothpick into tobacco seedlings and observing disease symptoms.

Visual estimates of weed control were made on 16 January and 9 April 1993. Weeds evaluated were yellow nutsedge (*Cyperus esculentus* L.), Florida pusley (*Richardia scabra* L.), purple cudweed (*Gnaphalium purpureum* L. var. *purpureum*), old field toadflax (*Linaria canadensis* (L.) Dum.) and cutleaf evening primrose (*Oenothera laciniata* Hill).

Stand counts from a 3.1 m linear row for both pepper and tobacco were recorded on 6 April. Height measurements were recorded for 20 plants dug at random and root gall ratings were made for each plot on 21 April. Galling on individual plants was rated on a scale of 1–5 where 1 = 0 galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75% and 5 = 76–100% of the root system galled. A wheat/corn seed bait (56 g of each) was randomly placed into a 15 cm diameter hole 3.8 cm deep in each plot on 17 November 1992. Each bait station was covered with soil, a 30 × 30 cm piece of black polyethylene and the bed covers. On 8 December, all bait plus soil in a 7.5 L sample was removed, placed into 2 ml polyethylene bags, stored in a cold room (4°C) and examined during the

following week. All soil and bait was sifted and observed for the presence of arthropods. The bait station procedure was repeated on 1 March 1993, and removed from the field and examined during the week of 22 March.

1993–94

The plot area had a history of continuous tobacco for 16 years, with no methyl bromide use for the three years prior to testing. The treatments were: methyl bromide at 489 kg ha⁻¹; metam-sodium at 935 L ha⁻¹ sprayed on the soil surface and incorporated 15 cm deep with a tractor-powered rototiller; dichloropropene+17% chloropicrin at 252 L ha⁻¹ chisel injected to 20 cm; dichloropropene+17% chloropicrin at 252 L ha⁻¹ chisel injected to 10 cm deep and mixed and incorporated 15 cm deep with a tractor-powered rototiller; a combination treatment of dichloropropene+17% chloropicrin at 126 L ha⁻¹ injected to a depth of 10 cm and metam-sodium at 935 L ha⁻¹ sprayed and incorporated to 15 cm and mixed with a tractor-powered rototiller; a combination treatment of dichloropropene+17% chloropicrin at 126 L ha⁻¹ injected to a depth of 10 cm and metam-sodium at 468 L ha⁻¹ sprayed on to the soil surface and incorporated 15 cm deep and mixed with a tractor-powered rototiller; dazmet at 387 kg ha⁻¹ applied to the soil surface and incorporated to 15 cm with a tractor-powered rototiller; and a non-treated control. All treatments were applied on 3 November except methyl bromide, which was applied on 4 November 1993. All plots were covered with 3 mil polyethylene film immediately after treatment, with the exception of the methyl bromide plot, which was covered with polyethylene film prior to treatment and the fumigant injected under the film manually. The average high temperature at a 10.2 cm soil depth during application was 18°C and average air temperature was 19°C. The treatments were arranged in a randomized complete block design with six replications of each treatment. Plots were 7.6 m long and 1.8 m wide.

Just prior to covering the plots with polyethylene film after treatment, toothpick cultures of *Phytophthora parasitica* var. *nicotianae*, in nylon mesh bags (two toothpicks per bag, three bags per plot), were placed 2–3 cm below the soil surface in each plot. These were recovered when the polyethylene film was removed on 6 December 1993 for the dazomet treatment and on 5 January 1994 for the other treatments, and tested for viability by reculturing, microscopic examination and inoculation trials. Soil samples collected on 20 January 1994 were assayed for populations of *Pythium* (*P. irregulare* Buisman and unidentified *Pythium* sp.) and *Rhizoctonia solani* AG-4 (Henis *et al.*, 1978; Jeffers and Martin, 1986).

On 25 January 1994, after aeration, two rows of 'Pip' bell pepper were seeded at 79 seeds m⁻¹ in the center of the plot, and two rows of 'Coker 371 Gold' and two rows of 'K-326' tobacco seeded at 63 seeds m⁻¹ on either side of the pepper. The plots were again covered with polyethylene film to protect them from the weather. Plots were fertilized and

watered as required, as recommended by the Georgia Cooperative Extension Service (Moore *et al.*, 1993).

A wheat/corn seed bait (56 g of each) was randomly placed into a hole (15.2 cm diameter $\times$ 3.8 cm deep) in each plot on 23 February 1994. Each bait station was covered with soil and seeds were allowed to germinate. Beginning on 16 March and continuing until 23 March, all baits plus soil in a 7.57 L sample were removed from all plots, one replication each day, and returned to the laboratory. All soil and bait was sieved, sorted and examined for the presence of arthropod pests.

Emergence was determined on 3 March 1994 by counting the number of plants in a 3.1 m section of the inside row of tobacco for each cultivar, and on 7 March 1994 for pepper. Vigor ratings for plots were recorded on 8 April 1994 using a 1–10 scale where 1 = least vigorous and 10 = most vigorous.

Weed control data were collected on 5 April 1994 by visually estimating the control of weeds in plots relative to the non-treated control. Weeds present were cutleaf evening primrose, purple cudweed, yellow nutsedge and Florida pusley. Twenty plants each of 'K-326', 'Coker 371 Gold' and 'Pip' pepper were removed from each plot on 15 April 1994 and the length of plants recorded.

1994–95

The plot area had a history of continuous tobacco production for 17 years with no use of methyl bromide at least three years before testing. The soil was turned, 25–30 cm deep with a moldboard plow, disc harrowed, rototilled and seedbeds formed prior to test initiation. Treatments were applied on 7 November 1994 as follows: metam-sodium at 468 L ha⁻¹; dichloropropene+17% chloropicrin at 126 L ha⁻¹; a combination of metam-sodium at 468 L ha⁻¹ and dichloropropene+17% chloropicrin at 126 L ha⁻¹ with and without polyethylene film; a combination of metam-sodium at 234 L ha⁻¹ and dichloropropene+17% chloropicrin at 63 L ha⁻¹; and a combination of metam-sodium at 117 L ha⁻¹ and dichloropropene+17% chloropicrin at 63 L ha⁻¹. All treatments except the one noted were sealed with a 3 mil polyethylene plastic immediately after treatment. The treatment not sealed with polyethylene film was sealed using a tractor-drawn soil cultipacker. Methyl bromide at 489 kg ha⁻¹ was injected under the 3 mil polyethylene film manually on 7 November. The dichloropropene+17% chloropicrin was applied by injecting the materials through chisels into the soil to a depth of 15–20 cm and incorporating with a tractor-powered rototiller. Metam-sodium application was as previously described for 1993–94. For treatments which had two of the materials the dichloropropene+17% chloropicrin was chiselled into the soil before the metam-sodium was sprayed on the soil surface and the chemicals mixed with a rototiller into the soil. Cultures of *P. parasitica* var. *nicotianae* in nylon mesh bags were buried in plots to a depth of 2–3 cm after treatment, but before 3 ml polyethylene film was applied. The polyethylene film was removed from the plots on 3 January 1995 and the plots were

allowed to aerate. Plots were rototilled on 13 and 17 January 1995, and seeded to 'K-326' and 'Coker 371 Gold' on 18 January 1995 at the rate of 63 seeds m⁻² using a Stanhay planter. Plots were fertilized and irrigated with water as required based on recommendations from the Georgia Cooperative Extension Service (Moore *et al.*, 1993).

Soil samples for fungal assay were collected on 3 November 1994 and 12 January 1995. Cultures of *P. parasitica* var. *nicotianae* placed in nylon mesh bags were buried in the plots at a 2.5 cm depth immediately after fumigation but before polyethylene film was applied. The cultures were removed from the plots when the covers were removed on 3 January 1995 and tested for viability. Soil samples for nematodes assay were taken on 3 November 1994, 9 January 1995, 7 April 1995 and 30 June 1995. Plant stand counts were recorded on 15 March 1995. Vigor ratings were made on 3 March and 13 April 1995. Transplant lengths were measured on 13 April 1995. On 13 January 1995 and 4 April 1995 plots were rated for control of the following weeds: henbit (*Lamium amplexicaule* L.), cutleaf evening primrose, Carolina geranium (*Geranium carolinianum* L.), southern crabgrass (*Digitaria sanguinalis* (L.) Scop.), yellow nutsedge and purple cudweed. On 17 March 1995 plots were rated for vegetable weevil (*Listroderes difficilis* Germar), damaged plants and mole cricket (*Scapteriscus* spp.) tunnels.

Data analysis

Data were analyzed by ANOVA or GLM procedures of SAS (SAS, 1985). Data for soil fungal populations were transformed as necessary (square root transformations for small numbers [<100] and log₁₀ for large numbers [>100] for statistical analyses) but all data are reported as non-transformed values. Significant differences among means were determined by Fisher LSD, Duncan's multiple range test, or Waller-Duncan ratio *t*-tests at $P=0.05$ (Steel and Torrie, 1960; Waller and Duncan, 1969).

Results

1992–93

Soil surface temperature under the polyethylene film and soil temperatures at 10 cm under the film ranged from 10 to 23°C and 11 to 20°C, respectively, during the trial (November 1992–April 1993). An unusual pungent odor persisted from plots treated with a combination of metam-sodium and dichloropropene+17% chloropicrin even after several weeks of aeration in each of the trials. The odor was distinctly different from any of the parent materials, but was distinctly chemical in nature. Plots treated with high rates of the combination occasionally experienced early stunting, but also resulted in high pest control.

There were no significant differences in the total number of bacteria before or after fumigation. Rifampicin-resistant mutants of *C. michiganensis* subsp. *michiganensis* were recovered from all treat-

ments and populations ranged from 6.4×10^5 to 3.5×10^6 cfu g⁻¹ soil (data not shown).

No significant differences in populations of soilborne fungi among treatments occurred before soil treatment. The methyl bromide 1992-93 treatment did not reduce soilborne fungal population densities below those of other fumigants. Populations of soilborne fungi were low and in only a few of the target fungi evaluated were differences between treated and non-treated plots detected (Table 2). Generally fungal population densities were decreased by all the fumigant treatments.

Total fungal population densities were reduced only by metam-sodium and Telone C-17 dichloropropene+17% chloropicrin combination, metam-sodium alone and dazomet.

Nematode populations were low initially and remained low throughout the test period (Table 2). Only chloropicrin reduced numbers of ring nematode, *Cricemella ornata* (Raski) Luc+Raski. All treatments reduced population densities of *Meloidogyne* sp. juveniles as compared to the non-treated plots (14 January).

Toothpicks infested with *P. parasitica* var. *nicotianae* recovered from the plots after soil treatment were evaluated for viability by both microscopic inspection and bioassay in tobacco plants. All cultures

recovered from the non-treated control were viable (Table 2). Culture viability was variable among treatments and cultures were eliminated by chloropicrin but not other treatments.

All plots were evaluated for winter-weed control by comparing weed densities in each treatment to the non-treated control. Control of purple cudweed at the time of tobacco and pepper seeding was 90-95% by all treatments (Table 3). However, by April differences in control among treatments were evident although none were different from the methyl bromide treatment. Similar trends occurred for cutleaf evening primrose control, except for chloropicrin which was the least effective of all treatments. Old field toadflax was effectively controlled by all treatments.

All treatments increased stand counts of pepper over the control, but only metam-sodium at 935 L ha⁻¹, chloropicrin and dazomet increased tobacco stand counts (Table 4). Plant height of pepper plants was increased by methyl bromide, metam-sodium (935 L ha⁻¹), chloropicrin and dazomet. Only metam-sodium (935 L ha⁻¹) increased tobacco heights.

Bait stations were initiated on 8 December 1992 and examined on 22 March 1993, and no wireworms (*Conoderus* spp.), grubs (*Scarabaeidae*) or mole

Table 2. Effects of soil fumigation on numbers of colony-forming units (cfu) of fungi on selective media and nematodes recovered from 150 cm³ of soil (1992-93)

Treatment	Rate	Application method ^a	Number of cfu g ⁻¹ soil				No. <i>Cricemella ornata</i> 150 cm ³ soil 9 Dec. 1992	No. <i>Meloidogyne</i> sp. juveniles 150 cm ³ soil 14 Jan. 1993	<i>P. parasitica</i> var. <i>nicotianae</i> viability (%)
			<i>Phythium</i> spp.	<i>Fusarium solani</i>	<i>Trichoderma</i> spp.	Total fungi			
Methyl bromide	489 kg ha ⁻¹	I	0 a ^b	0 b ^b	7764 ab ^a	10676 ab ^b	5 ab ^c	0 b ^c	58 ^a
Metam-sodium	935 L ha ⁻¹	SR	0 a	0 b	0 b	1941 b	4 ab	0 b	67
Metam-sodium+1,3-D, C17	467 L ha ⁻¹ +93 L ha ⁻¹	SR+I	0 a	0 b	0 b	1941 b	6 ab	0 b	25
1,3-D, C-17	187 L ha ⁻¹	I	0 a	0 b	28144 a	30085 a	3 ab	0 b	75
1,3-D, C-35	187 L ha ⁻¹	I	0 a	0 b	7764 ab	10675 ab	3 ab	0 b	58
Chloropicrin	56 L ha ⁻¹	I	28 a	32 b	6793 b	11646 ab	0 b	0 b	0
Dazomet	387 kg ha ⁻¹	GR	0 a	0 b	0 b	2911 b	1 ab	0 b	83
Non-treated	—	—	21 a	518 a	970 b	26204 a	10 a	4 a	100

^aI = injected; SR = sprayed and rototilled; GR = granular applied and rototilled into soil. ^bMeans followed by the same letter are not significantly different according to Fisher's LSD at $P = 0.05$. Statistical analysis was done after square root or logarithmic transformation; data are non-transformed values. ^cMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test, $P = 0.05$.

Table 3. Control of weeds by selected chemical treatments based on percentage control of non-treated plots (1992-93)

Treatment	Rate	Application method ^a	<i>G. purpureum</i> var. <i>purpureum</i>		<i>O. laciniata</i>		<i>L. canadensis</i> 9 Apr. 1993
			16 Jan. 1993	9 Apr. 1993	16 Jan. 1993	9 Apr. 1993	
Methyl bromide	489 kg ha ⁻¹	I	93 a ^b	85 abc	93 a	83 a	91 a
Metam-sodium	935 L ha ⁻¹	SR	95 a	95 a	95 a	94 a	95 a
Metam-sodium+1,3-D, C-17	467 L ha ⁻¹ +93 L ha ⁻¹	SR+I	95 a	94 a	96 a	93 a	95 a
1,3-D, C-17	187 L ha ⁻¹	I	95 a	88 ab	95 a	90 a	94 a
1,3-D, C-35	187 L ha ⁻¹	I	90 a	85 abc	91 a	88 a	95 a
Chloropicrin	56 L ha ⁻¹	I	94 a	75 c	94 a	65 b	91 a
Dazomet	387 kg ha ⁻¹	GR	95 a	81 bc	95 a	92 a	93 a
Non-treated	—	—	0	0	0	0	0

^aI = injected; SR = sprayed and rototilled; GR = granular applied and rototilled into soil. ^bMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

Table 4. Stand counts and plant height measurements of tobacco and pepper from plots treated with soil fumigants (1992-93)

Treatment	Rate	Application method ^a	Pepper stand ^b 6 Apr. 1993	Tobacco stand ^b 6 Apr. 1993	Plant height ^c (cm)	
					Pepper 21 Apr. 1993	Tobacco 21 Apr. 1993
Methyl bromide	489 kg ha ⁻¹	I	51.5 a ^d	83.3 ab	10.6 bc	24.6 b
Metam-sodium	935 L ha ⁻¹	SR	54.3 a	113.0 a	13.5 a	36.2 a
Metam-sodium+1,3-D, C-17	467 L ha ⁻¹ +93 L ha ⁻¹	SR+I	39.8 a	84.8 ab	9.9 bcd	25.5 b
1,3-D, C-17	187 L ha ⁻¹	I	49.5 a	79.5 ab	9.4 cd	25.0 b
1,3-D, C-35	187 L ha ⁻¹	I	52.0 a	80.8 ab	9.1 cd	21.4 b
Chloropicrin	56 L ha ⁻¹	I	58.5 a	109.5 a	12.1 ab	28.6 ab
Dazomet	387 kg ha ⁻¹	GR	47.3 a	109.5 a	10.6 bc	28.7 ab
Non-treated	—	—	4.8 b	50.0 b	7.5 d	20.2 b

^aI = injected; SR = sprayed rototilled; GR = granular applied and rototilled into soil. ^bAll plants in two center rows of a 3.1 m section of bed were counted. ^c20 plants chosen randomly from two center rows in a 3.1 m section of bed were measured in centimeters. Plant height was measured from soil surface to tip of longest leaf. ^dMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

crickets (*Scapteriscus* spp.) were detected in any plots, suggesting a low indigenous population.

1993-1994

All treatments except methyl bromide reduced the cfu g⁻¹ for *Pythium* species (Table 5). All treatments reduced *R. solani* cfu to below detectable levels, compared to 10 for the non-treated plots. Cultures of *P. parasitica* var. *nicotianae* recovered from plots were immediately evaluated for viability (Table 5). All treatments were effective in killing the fungus while 15 of the 18 cultures in the non-treated control remained viable. Nematode population densities were low and all treatments reduced numbers of *C. ornata* by 12 May 1994 but differences were not significant (Table 5).

Arthropod pressure was low but almost all treatments suppressed numbers of wireworms and grubs (Table 5). Numbers of seedcorn maggots, *Delia platura* (Meigen), and rove beetles, Staphylinidae, were unaffected by the fumigants.

All treatments controlled cutleaf evening primrose and purple cudweed as compared to the non-treated control (Table 6) on 21 January 1994 at seeding. Good control of purple cudweed was provided by all treatments except dichloropropene+17% chloro-

picrin alone, incorporated either shallow or deep. Dazomet and metam-sodium+dichloropropene+17% chloropicrin at 468 L ha⁻¹ were less effective than methyl bromide for controlling yellow nutsedge. All treatments effectively controlled Florida pusley, however, metam-sodium alone provided better control than dichloropropene+17% chloropicrin shallow incorporated.

Stand counts for 'Coker 371 Gold' tobacco were increased over the non-treated control by all treatments except methyl bromide (Table 7). All treatments except dichloropropene+17% chloropicrin applied, by shallow chisel and rototilled increased stand counts of 'K-326' tobacco over the non-treated control. All treatments increased stand counts of 'Pip' pepper over the non-treated control.

Dazomet and the combination treatments of metam-sodium plus dichloropropene+17% chloropicrin increased the vigor of 'Coker 371 Gold' tobacco (Table 7). Dazomet, the combination treatment of metam-sodium plus dichloropropene+17% chloropicrin and metam-sodium alone increased the vigor of 'K-326' tobacco. The vigor rating of 'Coker 371 Gold' was increased by the combination of metam-sodium plus dichloropropene+17% chloropicrin treatment at both rates and by the high rate of the combination for 'K-326' compared to methyl bromide. All treatments increased the vigor of 'Pip'

Table 5. Effect of soil chemical treatments on populations of fungi, insects and nematodes (1993-94)

Treatment	Rate	Application method ^a	<i>Pythium</i> spp. (CFU/g) ^b	<i>R. solani</i> AG4 (CFU/100 g)	Viable cultures <i>P. parasitica</i> var. <i>nicotianae</i> (%)	<i>C. ornata</i> No./150 cc soil		Number per plot ^d	
						24 Jan. 1994	12 May 1994	<i>Conoderus</i> spp.	<i>Scarabaeidae</i>
Methyl bromide	489 kg ha ⁻¹	I	59 a ^c	0 b	0	51 a	1 a	0.3 b	0.5 ab
Metam-sodium	935 L ha ⁻¹	SR	1 b	0 b	0	72 a	4 a	0.8 ab	0.0 b
Metam-sodium+ 1,3-D, C-17	935 L ha ⁻¹ +126 L ha ⁻¹	SR+ I (shallow)	0 b	0 b	0	83 a	3 a	0.8 ab	0.0 b
1,3-D, C-17	252 L ha ⁻¹	I (deep)	2 b	0 b	0	80 a	8 a	0.0 b	0.0 b
1,3-D, C-17	252 L ha ⁻¹	I (shallow) R	1 b	0 b	0	63 a	5 a	0.0 b	0.0 b
Metam-sodium+ 1,3-D, C-17	468 L ha ⁻¹ +126 L ha ⁻¹	SR+ I (shallow)	1 b	0 b	0	62 a	3 a	0.0 b	0.0 b
Dazomet	387 kg ha ⁻¹	GR	26 b	0 b	0	105 a	5 a	0.3 b	0.0 b
Non-treated	—	—	139 a	10 a	83	75 a	23 a	1.8 a	1.0 a

^aI = injected; SR = sprayed rototilled; GR = granular applied and incorporated with rototiller; R = rototilled. ^bcfu = colony-forming units. ^cMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test or the Waller-Duncan K-ratio test. ^dWireworms (*Conoderus* spp.) and grubs (*Scarabaeidae*) were enumerated on 16-23 Mar. 1994.

Table 6. Control of weeds by selected soil treatments based on percentage control of non-treated plots (1993-94)

Treatment	Rate	Application method ^a	<i>O. laciniata</i> % control 21 Jan. 1994	<i>G. purpureum</i> var. <i>purpureum</i>		<i>C. esculentus</i> % control 5 Apr. 1994	<i>R. scabra</i> % control 5 Apr. 1994
				21 Jan. 1994	5 Apr. 1994		
1 Methyl bromide	489 kg ha ⁻¹	I	100	100	90 ab ^b	95 a	95 ab
2 Metam-sodium	935 L ha ⁻¹	SR	100	100	88 ab	92 ab	95 a
3 Metam-sodium+ 1,3-D, C-17	935 L ha ⁻¹ + 126 L ha ⁻¹	SR+I (shallow)	100	100	94	95 a	94 ab
4 1,3-D, C-17	252 L ha ⁻¹	I (deep)	100	100	85 b	93 a	95 ab
5 1,3-D, C-17	252 L ha ⁻¹	I (shallow) R	100	100	85 b	91 ab	93 b
6 Metam-sodium+ 1,3-D, C-17	468 L ha ⁻¹ + 126 L ha ⁻¹	SR+I (shallow)	100	100	92 a	86 b	94 ab
7 Dazomet	387 kg ha ⁻¹	GR	100	100	92 a	71 c	94 ab
8 Non-treated	—	—	0	0	0	0	0

^aI = injected; SR = sprayed rototilled; GR = granular applied and rototilled into soil; R = rototilled. ^bMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

pepper, but metam-sodium alone increased the vigor of pepper over the methyl bromide treatment.

The plant height of 'Coker 371 Gold' was increased by metam-sodium plus metam-sodium plus dichloropropene+17% chloropicrin combinations and dazomet (Table 8). The dichloropropene+17% chloropicrin applied by deep chisel, the combination of metam-sodium, dichloropropene+17% chloropicrin at the low rates and dazomet treatments increased plant length of 'K-326' tobacco. All treatments except dichloropropene+17% chloropicrin applied by deep chisel increased the plant length of 'Pip' pepper.

1994-95

Soil surface temperatures under the polyethylene film ranged from 8°C to 21°C and temperatures at a 10 cm soil depth ranged from 9°C to 20°C during the trial (November 1994-April 1995).

Population densities of *R. solani* and *Pythium* spp. were not significantly different in the plot area prior to fumigation. All treatments reduced populations of *R. solani* and *Pythium* spp. (Table 8).

The numbers of *Meloidogyne* sp. second stage juveniles in the soil were low and no differences in

numbers were detected between the treated and non-treated plots. Root gall indices of 'K-326' taken on 30 June 1995 were reduced by all treatments except metam-sodium (234 L ha⁻¹) plus dichloropropene+17% chloropicrin (Table 8). Only metam-sodium alone did not reduce root gall indices on 'Coker 371 Gold'.

Insect numbers were low during the test period but differences in control were detected among treatments (Table 8). All fumigants except the combination metam-sodium (117 L ha⁻¹) plus dichloropropene+17% chloropicrin (63 L ha⁻¹) reduced damage from vegetable weevil. The number of mole cricket tunnels per plot was reduced by all treatments except metam-sodium alone and the lowest rate of the combination treatment metam-sodium (117 L ha⁻¹) plus dichloropropene+17% chloropicrin (63 L ha⁻¹).

All treatments except the treatment without polyethylene film controlled henbit, cutleaf evening primrose, Carolina geranium, southern crabgrass, yellow nutsedge and purple cudweed (Table 9). The low rate of the combination treatment of metam-sodium (117 L ha⁻¹) plus dichloropropene+17% chloropicrin (63 L ha⁻¹) and the treatment without a polyethylene film did not control yellow nutsedge

Table 7. Effect of selected chemical treatments on plant survivability, vigor and size (1993-94)

Treatment	Rate	Application method ^a	Stand counts (no. of plants per 3.1 m) 3 Mar. 1994			Vigor rating ^b (1-10 scale) 8 Apr. 1994			Plant height ^d (cm) 15 Apr. 1994		
			'C-371-G'	'K-326'	'Pip'	'C-371-G'	'K-326'	'Pip'	'C-371-G'	'K-326'	'Pip'
Methyl bromide	489 kg ha ⁻¹	I	164 ab ^c	146 ab	82 a	2.3 bc	3.1 bc	3.3 b	22 abcd	23 ab	17 ab
Metam-sodium	935 L ha ⁻¹	SR	206 a	167 a	90 a	3.0 abc	4.8 ab	5.3 a	25 abc	33 ab	18 a
Metam-sodium+ 1,3-D, C-17	935 L ha ⁻¹ + 126 L ha ⁻¹	SR+I (shallow)	184 a	135 ab	102 a	4.5 a	5.3 a	4.8 ab	28 ab	31 ab	17 ab
1,3-D, C-17	252 L ha ⁻¹	I (deep)	189 a	162 ab	92 a	2.3 bc	2.8 bc	3.6 ab	18 cd	36 a	15 bc
1,3-D, C-17	252 L ha ⁻¹	I (shallow) R	180 a	128 bc	94 a	2.3 bc	2.5 c	4.2 ab	19 bcd	24 ab	17 ab
Metam-sodium+ 1,3-D, C-17	468 L ha ⁻¹ + 126 L ha ⁻¹	SR+I (shallow)	190 a	156 ab	92 a	4.7 a	5.5 a	4.8 ab	32 a	34 a	19 a
Dazomet	387 kg ha ⁻¹	GR	190 a	144 ab	102 a	3.8 ab	4.8 ab	4.3 ab	26 abc	34 a	17 ab
Non-treated	—	—	125 b	97 c	56 b	2.0 c	1.8 c	1.3 c	15 d	15 b	13 c

^aI = injected; SR = sprayed rototilled; GR = granular applied and rototilled into soil; R = rototilled. ^bVigor rating is an estimate of overall plant health, where 1 = very low plant vigor and 10 = very high plant vigor. ^cMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test. ^dPlant height was measured from soil surface to the tip of the longest leaf.

Table 8. Fungal population densities, root-gall indices and insect damage as influenced by soil chemical treatments (1994-95)

Treatment	Rate	Application method ^a	<i>Rhizoctonia solani</i> AG-4 (CFU/100 g)	<i>Pythium</i> spp. (CFU/100 g)	Root gall index (1-5 scale) 30 June 1995		<i>L. difficilis</i> damage (no./plants) ^c	<i>Scaptomyza</i> spp. tunnels (no./plots) ^c
					'K-326'	'C-371G'		
Methyl bromide	489 kg ha ⁻¹	I	0 a ^b	0 a	1.1 b	1.0 b	0.3 c	0.2 bc
Metam-sodium	468 L ha ⁻¹	SR	0 a	0 a	1.2 b	1.4 ab	0.7 c	1.0 abc
1,3-D, C-17	126 L ha ⁻¹	IR	0 a	16 a	1.1 b	1.1 b	1.7 b	0.3 bc
Metam-sodium + 1,3-D, C-17	468 L ha ⁻¹ + 126 L ha ⁻¹	SR+IR	0 a	0 a	1.1 b	1.0 b	0.2 c	0.0 c
Metam-sodium + 1,3-D, C-17	234 L ha ⁻¹ + 63 L ha ⁻¹	SR+IR	0 a	1 a	1.3 ab	1.1 b	0.5 c	0.0 c
Metam-sodium + 1,3-D, C-17	117 L ha ⁻¹ + 63 L ha ⁻¹	SR+IR	0 a	0 a	1.0 b	1.1 b	2.1 ab	1.2 ab
Metam-sodium + 1,3-D, C-17	468 L ha ⁻¹ + 126 L ha ⁻¹	SR (no poly film) + IR (cultipacker)	0 a	3 a	1.1 b	1.1 b	0.2 c	0.2 bc
Non-treated	—	—	8 h	154 b	1.5 a	1.6 a	2.7 a	1.5 a

^aI = injected; SR = sprayed rototilled; IR = injected and rototilled. All treatments covered with polyethylene film unless noted. ^bMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test or the Waller-Duncan K -ratio test. ^cMean number of plants damaged by vegetable weevil (*Listroderes difficilis*) per plot and number of mole cricket (*Scaptomyza* spp.) tunnels per plot measured on 17 March 1995.

well. However, higher rates of the same combination with a polyethylene film were effective.

Stand counts of 'Coker 371 Gold' tobacco were increased by metam-sodium, dichloropropene and the lowest rates of the combination treatment of metam-sodium plus dichloropropene+17% chloropicrin covered with polyethylene film (Table 10). Stand counts of 'K-326' were increased by all treatments except methyl bromide and metam-sodium (234 L ha⁻¹) plus dichloropropene+17% chloropicrin (63 L ha⁻¹). Vigor ratings, recorded on 13 April, and plant heights were increased by all treatments for both tobacco cultivars over the non-treated control. Plots treated with methyl bromide and dichloropropene+17% chloropicrin had higher vigor ratings for 'Coker 371 Gold' tobacco than other treatments.

Discussion

It is difficult to simultaneously evaluate the many parameters that are required of an effective soil

fumigant. Each growing season and each field location has unique parameters that influence the pest problems most predominant in that year. Although different experimental locations were selected each year, some pests were not severe enough to fully evaluate the efficacy of the fumigants on all pests where performance would be expected. However, areas that were well evaluated were weeds, fungal dynamics, stand establishment and plant vigor.

Many of the treatments that were evaluated performed well in controlling multiple pest problems on tobacco and pepper. Although it was difficult to determine the cause of reduced stands of tobacco and pepper seedlings under polyethylene film, we suspect that fungi and bacteria that escaped the chemical treatment were the primary cause. Studies evaluating the population dynamics of fungi in the soil suggest that most treatments evaluated do an acceptable job in eliminating or reducing pathogenic fungi in the soil. The studies with cultures of *P. parasitica* var. *nicotianae* in plastic mesh bags also support these observations.

Table 9. Control of weeds by various soil chemical treatments based on percentage control of non-treated plots (1994-95)

Treatment	Rate	Application method ^a	% control					
			13 Jan. 1995			4 Apr. 1995		
			<i>L. amplexicaule</i>	<i>O. luciniata</i>	<i>G. carolinianum</i>	<i>D. sanguinalis</i>	<i>C. esculentus</i>	<i>G. purpureum</i> var. <i>purpureum</i>
1 Methyl bromide	489 kg ha ⁻¹	I	100 a ^b	100 a	100 a	95 a	95 a	87 a
2 Metam-sodium	468 L ha ⁻¹	SR	100 a	100 a	100 a	95 a	92 a	92 a
3 1,3-D, C-17	126 L ha ⁻¹	IR	98 a	95 a	95 a	94 a	85 ab	78 b
4 Metam-sodium + 1,3-D, C-17	468 L ha ⁻¹ + 126 L ha ⁻¹	SR+IR	99 a	99 a	99 a	95 a	95 a	93 a
5 Metam-sodium + 1,3-D, C-17	234 L ha ⁻¹ + 63 L ha ⁻¹	SR+IR	100 a	100 a	100 a	94 a	90 a	92 a
6 Metam-sodium + 1,3-D, C-17	117 L ha ⁻¹ + 63 L ha ⁻¹	SR+IR	99 a	96 a	96 a	95 a	77 b	88 a
7 Metam-sodium + 1,3-D, C-17	468 L ha ⁻¹ + 126 L ha ⁻¹	SR (no poly film) + IR (cultipacker)	82 b	81 b	89 b	53 b	50 c	30 c
8 Non-treated	—	—	0	0	0	0	0	0

^aI = injected; SR = sprayed rototilled; IR = injected and rototilled. All plots covered with polyethylene film unless otherwise noted. ^bMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

Table 10. Stand counts, vigor ratings and plant heights of two tobacco cultivars in soil chemical treated plots (1994-95)

Treatment	Rate	Application method ^a	Stand counts (no. plants/3.1 m of row) 15 Mar. 1995		Vigor rating ^b (1-10 scale) 13 Apr. 1995		Plant height ^c (cm) 13 Apr. 1995	
			Cultivar		Cultivar		Cultivar	
			'C-371 G'	'K-326'	'C-371 G'	'K-326'	'C-371 G'	'K-326'
Methyl bromide	489 kg ha ⁻¹	I	86 abc ^d	104 ab	8.7 a	9.0 a	27.8 a	30.5 a
Metam-sodium	468 L ha ⁻¹	SR	99 ab	124 a	6.7 bc	7.5 bc	21.5 ab	25.1 bc
1,3-D, C-17	126 L ha ⁻¹	IR	117 a	130 a	7.8 ab	8.7 ab	24.8 ab	28.7 ab
Metam-sodium+	468 L ha ⁻¹ +	SR+IR	90 abc	125 a	7.2 bc	7.3 bc	22.9 ab	23.7 c
1,3-D, C-17	126 L ha ⁻¹							
Metam-sodium+	234 L ha ⁻¹ +	SR+IR	98 ab	107 ab	6.5 bc	7.3 bc	21.0 b	26.5 abc
1,3-D, C-17	63 L ha ⁻¹							
Metam-sodium+	117 L ha ⁻¹ +	SR+IR	109 ab	116 a	7.3 c	8.3 ab	23.6 ab	27.6 abc
1,3-D, C-17	63 L ha ⁻¹							
Metam-sodium+	468 L ha ⁻¹ +	SR (no film)+	76 bc	112 a	6.3 c	6.8 c	21.4 ab	24.8 bc
1,3-D, C-17	126 L ha ⁻¹	IR (cultipacker)						
Non-treated	—	—	55 c	79 b	2.4 d	3.0 d	13.6 c	16.6 d

^aI = injected; SR = sprayed and rototilled; IR = injected and rototilled. ^bMeans followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test. ^cVigor ratings were made on a scale of 1-10, where 1 = poor and 10 = excellent. ^dAll plants in a 1.6 m section of row were measured from soil surface to the tip of the longest leaf.

The presence of high populations of bacteria in fumigated soils after careful and aseptic sampling techniques, as well as recovery of *C. michiganensis* subsp. *michiganensis* with resistance to rifampicin, indicates none of the fumigants had a significant effect on bacterial populations.

Plant vigor and plant size are also good measures of overall activity in reducing pest problems on germinating seeds of tobacco and pepper. Several treatments appeared to perform well, including metam-sodium, methyl bromide, dazomet and combinations of metam-sodium plus dichloropropene+17% chloropicrin. Currently, dazomet is still not labelled for use on tobacco or pepper in the US. The estimated cost for dazomet at the rate evaluated is several times greater than methyl bromide and may be prohibitive. Johnson and Feldmesser (1987) listed dazomet as obsolete, and thus its availability is questionable in the US.

The standard treatment, methyl bromide (489 kg ha⁻¹), was not the top performer of the fumigants evaluated in two of the three years studied. In 1992-93 and 1993-94 the methyl bromide treatment was not different from the non-treated control in important parameters such as stand establishment, plant height measurements and vigor ratings of tobacco. However, in 1994-95 the methyl bromide treatment performed better, as evidenced by high vigor ratings. This study did not address gas concentrations under the polyethylene film and some inconsistencies in methyl bromide performance may be related to low concentrations due to unknown factors.

Weed control was very good by almost all of the treatments. A notable exception was dazomet, which controlled yellow nutsedge poorly (Table 6). The combination treatment of metam-sodium (468 L ha⁻¹) plus dichloropropene+17% chloropicrin (126 L ha⁻¹) that was not covered with polyethylene film after treatment in 1994-95 (Table 9) also gave poor weed control. Although results of that treatment were encouraging, optimum performance will require

the use of a polyethylene film after treatment (Youngson and Goring, 1962).

The numbers of nematodes and insects were low in all locations in which the tests were initiated. Most treatments were capable of controlling these low numbers although some treatments tended to perform better than others. However, with the low levels of both nematodes and insects, conclusions on the treatments activity in this area are difficult to make.

There are four fumigant nematicides available: chloropicrin, dichloropropene, methyl bromide and metam-sodium (Johnson and Feldmesser, 1987). These chemicals have been used alone and in various combinations for nematode soilborne fungi control on various crops for many years (Youngson and Goring, 1962; McCarter *et al.*, 1976a,b, 1978; Jaworski *et al.*, 1978; Johnson *et al.*, 1979b). Other non-volatile nematicides are registered for nematode control on some crops. From these chemicals a combination of dichloropropene+chloropicrin, a non-volatile nematicide+chloropicrin, a non-volatile nematicide+metam-sodium, or a non-volatile nematicide+dazomet in combination with specific herbicides appears to be viable candidate alternatives to methyl bromide. Our results on reduction of nematode population densities and root-gall indices in this study are promising. In future studies combinations of non-volatile nematicides such as fenamiphos and ethoprop plus a fungicide plus a herbicide should be evaluated. Combinations of specific pesticides for multiple pest control on other crops have been reported (Brodie *et al.*, 1968; Johnson *et al.*, 1975).

Many of the treatments were comparable to methyl bromide in the parameters evaluated. Plots treated with combinations of metam-sodium plus dichloropropene+17% chloropicrin covered with polyethylene film had high activity on the pests evaluated although some stunting (low vigor) was noted at the highest rates. This combination of fumigants has a broad spectrum of activity for the pests most often

encountered in the southeast USA. Further evaluation of these and other pesticide combinations is needed in areas of higher nematode and insect pressures to fully evaluate these alternatives to methyl bromide.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + Chloropicrin

[Insert Alternative]

Study: Methyl bromide alternatives in a bell pepper-squash rotation

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted	<u>X</u>
1b. Township caps	<u> </u>
1c. Alternative not acceptable in consuming country	<u> </u>
1d. Other (Please describe)	<u> </u>

Can be used on pepper, tomato, cucurbit crops and strawberries.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only

ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**Section II. Existing Research Studies on Alternatives to Methyl Bromide**1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Webster, Csinos, Johnson, Dowler, Summer, and Fery3. Publication and Date of Publication Crop Protection, 20014. Location of research study Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

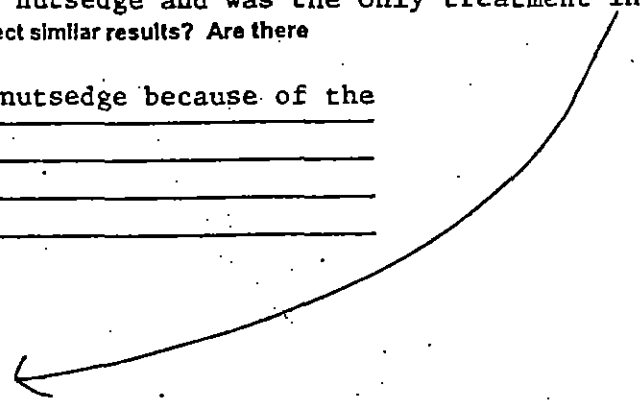
1,3-D + Chloropicrin (chisel)1,3-D + Chloropicrin (drip)6. Was crop yield measured in the study? Yes X No _____

7. Describe the effectiveness of the alternative in controlling pests in the study.

The studies were conducted in 1998 and 1999. In 1998, 1,3-D + C35 chisel treatment gave similar control of purple nutsedge as methyl bromide except that there was purple nutsedge that emerged at low levels that would likely reinfest the area. Also in 1999, there was no difference in purple nutsedge control from these alternatives relative to the no treated control. Methyl bromide in 1998 eliminated purple nutsedge and was the only treatment in

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Growers would not use this alternative for purple nutsedge because of the inconsistency of this product.

1999 to effectively control this weed at harvest. 

Research Summary Table

Alternative: 1,3-D + ChloropirrinStudy: Webster, Calnos, Johnson, Dowler, Sumner, and Fery, 2001

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Purple Nutsedge Density (1998)						Pest 2: Purple Nutsedge Density (1999) ¹						Pepper Yield (kg/plot)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
2	1,3-D + chloropirrin (chisel)	148 + 83 kg/ha	harvest	2					harvest	105					11.7 6.35
3	1,3-D + chloropirrin (drip)	146 + 83 kg/ha	harvest	23					harvest	145					2.19 0.48
4	methyl bromide	440 kg/ha	harvest	0					harvest	120					7.81 10.48
6	nontreated			64					harvest	50					0.54 0.45

Comments: ¹ estimates from graph in study report; densities reflect no. per plot; yield data = "Camelot" | "Charleston Belle".

If a consortium is submitting this application, the data for this table should reflect a representative user.													
Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.												
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.												
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.												
Col. D: Formulation	Enter the formulation or the % of active ingredient.												
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.												
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by hand user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.												
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.												
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.												
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.												
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.												
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.													
A	B	C	D	E	F	G	H	I	J	K	L	M	
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)	
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)							
1,3-D + chloropicrin	nutsedge	1,3-D chloropicrin	83%	146 kg/ha	19	gal	\$ 13.10	\$ 75.00	80	100	1	\$ 403.90	
Non-Chemical Pest Control	Target Pests	Description										Cost/Area	
											Total	\$ 403.90	
Comments:													

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments:

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

1,3-D + Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No change

Methyl bromide alternatives in a bell pepper–squash rotation

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Abstract

Field studies were conducted to evaluate potential methyl bromide alternatives against multiple pests in a bell pepper (*Capsicum annuum* L.) – squash (*Cucurbita pepo* L.) cropping sequence. Early in the growing season, the most effective treatments in suppressing purple nutsedge (*Cyperus rotundus* L.) emergence through the polyethylene mulch were methyl bromide, methyl iodide, and chisel-injected 1,3-dichloropropene plus chloropicrin [1,3-D + C35 (chisel)]. However by the end of the season in 1999, only methyl bromide treatment had less purple nutsedge emerging through the polyethylene than the nontreated control. Each soil-applied treatment resulted in nematode-susceptible pepper plants with lower root-gall indices [*Meloidogyne* spp. (root knot nematode)] than the nontreated control, while there were no differences among treatments with the nematode-resistant pepper cultivar. Total fungi isolated from soil was lower in all treated plots relative to the nontreated control, with the exception of methyl iodide. However, methyl bromide was the only treatment that was consistently effective against *Pythium* spp. and *Fusarium* spp. A treatment of metham prior to planting squash was beneficial in reducing root-gall indices in plots treated with 1,3-D + C35 (chisel) and methyl bromide prior to the pepper crop. Methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) applied before pepper resulted in squash with lower root-gall indices than the nontreated control. Glyphosate applied between the first and second crop eliminated exposed weed foliage through the polyethylene mulch, possibly muting the effects of the second crop treatment on weed densities. Results of this study indicate that there are some potential methyl bromide alternatives available to growers for use in pest control, however there does not appear to be one broad-spectrum pesticide that will replace methyl bromide. Also, an effective control for nutsedge species within the pepper–squash cropping system is still elusive. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: *Cyperus rotundus*; *Fusarium* spp; *Meloidogyne incognita*; Methyl bromide; *Pythium* spp; Metham; Methyl iodide; 1,3-dichloropropene

1. Introduction

Methyl bromide is an effective soil fumigant used extensively prior to planting many vegetable and fruit crops to control a broad-spectrum of pests that include nematodes, soilborne plant pathogenic fungi, soilborne insects, and weeds. Methyl bromide has been used since the 1950s to eliminate pest problems in many minor-use crops. Many of these crops have a limited number of pesticide alternatives due to the high cost associated with the registration of a pesticide. This high cost coupled with the relatively low numbers of hectares of these crops

makes most pesticide manufacturers reluctant to register pesticides for minor-use crops. While this has been an important issue surrounding minor-use crops, it has been tempered by the availability of methyl bromide and its biocide activities. However, methyl bromide was listed as a Class I ozone depleting substance by the US Environmental Protection Agency in 1993 and its use is scheduled to be halted by the year 2005. While methyl bromide is used for post-harvest pest control of stored products and for pest control of buildings and other structures, it is estimated that 85% of methyl bromide is used in agriculture as a preplant soil fumigant for high value vegetable and agronomic crops (Julian et al., 1998). With the impending elimination of this valuable compound, growers will need viable alternatives to manage a wide range of pests.

Previous research has identified several potential pest management alternatives for methyl bromide in various

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cropping systems. Methyl iodide has been proposed as a methyl bromide replacement without the suspected depletion of the stratospheric ozone layer that is attributed to methyl bromide (Ohr et al., 1996). Becker et al. (1998) found that applications of methyl iodide at 168 kg/ha eliminated *Meloidogyne incognita* (Kofoid & White) Chitwood (southern root knot nematode) juveniles eight days after treatment and that root galling on lima beans [*Phaseolus lunatus* L. cv. Henderson] was suppressed to less than 1% at two months following treatment. Methyl iodide applied at rates as low as 28 kg/ha reduced populations of *M. incognita* to less than 3/100 cm³ of soil at five weeks after treatment in tomato (Noling and Gilreath, 1995). However, by 11 weeks after treatment the severity of root galls on tomato plants in the methyl iodide treatments was not different from the nontreated control. Laboratory studies indicated that methyl iodide was generally more biologically active on velvetleaf (*Abutilon theophrasti* Medik.) and Italian ryegrass (*Lolium multiflorum* Lam.) seeds than methyl bromide and optimum efficacy was related to soil hydration (Zhang et al., 1998).

Other potential methyl bromide replacements include metham, 1,3-dichloropropene, chloropicrin, and various combinations of these compounds. When applied in the fall of the year to nursery beds of bell pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentus* Miller), and tobacco (*Nicotiana tabacum* L.), metham efficacy was similar to methyl bromide plus chloropicrin (98:2) in 76 of 79 tested parameters which included crop vigor, winter annual weed control, soilborne fungal populations, nematode soil populations and nematode injury ratings (Csinos et al., 2000). In a transplant production system, the combination of metham + 1,3-dichloropropene + chloropicrin was similar to methyl bromide in control of weeds [yellow nutsedge (*Cyperus esculentus* L.), Florida pusley (*Richardia scabra* L.), and winter annual weed species], fungi (*Pythium* spp., *Rhizoctonia solani* Kühn), and crop response (stand count, crop vigor rating, and crop height) (Csinos et al., 1997). Other research found that plots treated with either 1,3-dichloropropene + chloropicrin or metham had lower tomato fruit yield, inferior control of yellow nutsedge, and higher fungal populations compared to the methyl bromide treated plots (Locascio et al., 1997).

The objective of this study was to determine the effects of soil chemical treatments on nematodes, weeds, soilborne plant pathogenic fungi, and crop response in a bell pepper-squash (*Cucurbita pepo* L.) cropping sequence in a plasticulture production system. In addition, bell pepper cultivars resistant or susceptible to *M. incognita* were used in the sequence across all soil treatments in order to evaluate the residual effects of the resistant crops in suppressing nematode populations in the subsequent *M. incognita*-susceptible squash crop.

2. Materials and methods

2.1. General

Field studies were conducted in 1998 and 1999 at the Coastal Plain Experiment Station in Tifton, GA. The soil was a Dothan loamy sand (fine-loamy, siliceous thermic Plinthic Paleudults: 93% sand, 4% silt, 3% clay) with 0.5% organic matter and a soil pH of 6.0 to 6.5. The area was naturally infested with *Meloidogyne incognita* [(Kofoid & White), Chitwood race 1, southern root knot nematode], *Pythium* spp., *Fusarium* spp., and purple nutsedge (*Cyperus rotundus* L.). The land was previously planted to cowpea [*Vigna unguiculata* (L.) Walp. cv. Pinkeye Purplehull] as a summer cover crop and hairy vetch (*Vicia villosa* Roth) as a winter cover crop to increase native densities of *M. incognita*.

The soil was disk harrowed and moldboard plowed 25–30 cm deep. Dolomitic limestone (2240 kg/ha) and 5–10–15 fertilizer (560 kg/ha) were broadcast and incorporated to a depth of 8–10 cm with a tractor-mounted rototiller. Single beds (76 cm wide, 7.6 m long, and 15 cm high) were established with a bed shaper. A single drip irrigation tube with emitters spaced 30 cm apart with a flow rate of 30 ml/min/30 m was placed in the center of the bed under the polyethylene mulch for application of water, fertilizer, and some fumigants. Black 32 µm-thick (1.25 mil) polyethylene mulch covered each bed immediately following chisel injected and soil fumigant applications. Designated treatments were applied through the drip irrigation system the following day.

Seedlings for transplants were grown in a greenhouse in plastic trays (6.4 cm × 34.3 cm × 67.3 cm) containing 128 cells (3.8 cm diameter by 6.4 cm deep). Cells were filled with a dry mixture of vermiculite and sphagnum peat moss (35:65). Trays were placed in a vat of water containing 20–20–20 fertilizer at 0.6 g/l of water. After 12 h, the medium in each cell contained the maximum moisture for seeding. The medium in each cell was compressed to a depth of 1.3 cm from the bottom of the tray. One seed was placed in each cell and covered with dry medium. Within 8 h the dry medium contained adequate moisture for seed germination. Trays remained in vats until after seed germination and were monitored for adequate moisture. To begin the acclimation of seedlings to field conditions, plants were removed from the greenhouse and placed in a field environment several days prior to transplanting.

2.2. Bell pepper

Treatments were arranged as a split-split-plot, with soil treatments applied prior to bell pepper (first crop) as the main plots, chemigated soil treatments applied through irrigation tubing prior to squash (second crop) as subplots (described later in detail in the squash

Table 1
Main and subplot treatments applied to pepper and squash crops

	Application method	Rate	Date applied
<i>Main plot (first crop treatments)^a</i>			
Fenamiphos + metham	Broadcast to soil surface ^b + chemigated through drip tape ^c	6.7 kg ai/ha + 240 kg ai/ha	30 March 1998; 31 March 1999
Methyl bromide	Fumigated	440 kg ai/ha	13 April 1998; 30 March 1999
Methyl iodide	Chemigated through drip tape ^c	440 kg ai/ha	13 April 1998; 1 April 1999
1,3-dichloropropene (1,3-D)	Chemigated through drip tape ^c	136 kg ai/ha	13 April 1998
1,3-dichloropropene + chloropicrin [1,3-D + C35 (chisel)]	Chisel injected	146 kg ai/ha + 83 kg ai/ha	13 April 1998; 30 March 1999
1,3-dichloropropene + chloropicrin [1,3-D + C35 (drip)]	Chemigated through drip tape ^c	146 kg ai/ha + 83 kg ai/ha	13 April 1998; 31 March 1999
Nontreated control	—	—	—
<i>Sub-plot (second crop treatments)^d</i>			
Metham	Chemigated through drip tape ^c	240 kg ai/ha	21 July 1998; 26 July 1999
Nontreated control	—	—	—

^aMain plots were 3.6 m × 7.6 m and treatments applied prior to pepper crop.

^bGranular fenamiphos was applied to the soil surface and shallowly incorporated.

^cPlots were chemigated for 60 min using a pump that delivered 126 ml/min. Water was added to each treatment to a total volume of 7500 ml. Following each 60 min treatment application, the lines were flushed with water for 30 min into the treated plots prior to application of the next treatment. This system was equipped with pressure regulators that maintained a consistent 83 kPa through the irrigation tubing.

^dSub-plots were 1.8 m × 7.6 m, each main plot treatment was divided to receive subplot treatments that were applied prior to squash crop.

section), and nematode-resistant and nematode-susceptible bell pepper cultivar were the sub-subplots (Table 1). Main plots were 3.6 m wide and 7.6 m long and consisted of two subplots each 1.8 m wide and 7.6 m long. The subplots were planted to two rows of bell pepper, one of each cultivar, which constituted the sub-subplot.

To allow for aeration prior to crop transplanting, two rows of holes 8 cm in diameter and spaced 30 cm apart were cut into the polyethylene mulch of each bed at 10 and 14 days after the methyl bromide treatment in 1998 and 1999, respectively. Five days after holes were cut in the polyethylene, a single greenhouse-grown pepper plant was planted in each hole with one row of *M. incognita*-resistant 'Charleston Belle' and one row of *M. incognita*-susceptible 'Camelot' pepper per bed on 27 April 1998 and 16 April 1999.

All pepper plots were sprayed on a 7–10-day schedule with 2 kg ai/ha maneb (Manex, Griffin LLC, Valdosta, GA 31601) and 1.3 kg ai/ha copper hydroxide (Kocide, Griffin LLC, Valdosta, GA 31601) in a water volume of 187 l/ha for foliar disease control. All plots received liquid fertilizer injected through the drip irrigation system once a week for a total of 130 kg/ha of nitrogen, 48 kg/ha of P₂O₅, 27 kg/ha K₂O, and 1 kg/ha boron.

Twenty soil cores (2.5 cm-diameter, 25 cm-depth) for nematode assay were collected from each row of pepper at monthly intervals from March through July in 1998 and April through July in 1999. The samples from each row within a plot were pooled and a 150 cm³ subsample was processed by centrifugal flotation method to separ-

ate nematodes from the soil (Jenkins, 1964). A 100 cm³ subsample was assayed for populations of *Pythium* spp. (P₅ARP media) (Jeffers and Martin, 1986), *Fusarium solani* (Mart.) Sacc. and *Fusarium oxysporum* Schlecht. Fr. (modified PCNB) (Papavizas, 1967), *Aspergillus* spp., *Trichoderma* spp., *Penicillium* spp., and *Paecilomyces* spp. (OAES media) (Williams and Schmitthenner, 1960). Roots of five pepper plants from each plot were dug, washed in tap water, blotted dry with paper towels, and rated for root galls caused by *M. incognita* after final harvest. A scale ranging from 1 to 5 was used where 1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% of the root system with galls.

The total number of living plants per plot was recorded in May of each year. Some plants began to show symptoms of wilting even in the presence of adequate soil moisture 4–6 weeks after planting in 1998. The number of wilted and healthy plants was recorded on 10 June 1998 and 10 July 1998.

All fruit were hand-harvested, separated into marketable and cull, counted, and weighed in late June and early July. After the final harvest, all weeds growing in the hole in the polyethylene where the bell peppers or squash plants were planted and those penetrating through the polyethylene mulch were identified and counted. Due to the diversity of weeds that emerged through the crop holes, weeds were divided into two categories: purple nutsedge and other weeds. The other weeds included bermudagrass [*Cynodon dactylon* (L.) Pers.], cutleaf

eveningprimrose (*Oenothera lacinata* Hill), Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], goosegrass [*Eleusine indica* (L.) Gaertn.], pink purslane (*Portulaca pilosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), smallflower morningglory [*Jaquemontia tamnifolia* (L.) Griseb.], and Texas panicum (*Panicum texanum* Buckl.). After weeds were counted and identified, all pepper plants were cut at the soil surface and removed from the plots. All plots were sprayed with 2.2 kg ai/ha glyphosate to eliminate all existing weeds prior to applying treatments for the second crop.

2.3. Squash

Main plots (first crop soil treatments) were split into two treatments for the second crop. Subplots included a nontreated control and an application of metham chemigated through the irrigation tubing on 21 July 1998 and 26 July 1999 (Table 1). Squash cultivar 'Dixie' seedlings were produced in the greenhouse using the methods previously described. Seedlings were large enough to transplant 12–15 days after seeding and were transplanted in the holes between the original pepper plants on 5 August 1998 and 10 August 1999.

All plots of squash received liquid fertilizer through the drip irrigation system at three to four day intervals totaling 130 kg/ha of nitrogen, 57 kg/ha of P_2O_5 and 41 kg/ha K_2O over 12 applications. All squash plots were sprayed with 0.1 kg ai/ha mefenoxam and 1.6 kg ai/ha chlorothalonil (Ridomil Gold Bravo, Novartis Crop Protection, Inc., Greensboro, NC 27419) for control of crown and foliar diseases and 0.11 kg ai/ha permethrin (Pounce, FMC Corporation, Agricultural Products Group, Philadelphia, PA 19103) and 4.6 l ai/ha potassium salts of fatty acids (M-Pede, Mycogen Corporation, San Diego, CA 92121) for insect control on a 7–10 day interval.

Five squash plants were dug from each plot following the last harvest and rated for galls as previously described for pepper. Squash fruit were harvested three times a week for 2–3 weeks. Fruit were graded as either marketable or cull, and the number and weight at each harvest were determined. After the final harvest, weed populations were determined and root galls were rated from five plants as previously described.

2.4. Data analysis

All data were subjected to analysis of variance and means separated using Fisher's Protected LSD Test or Duncan's Multiple Range Test, both at an alpha level of 0.05. Prior to analysis of variance, data on pest populations were square-root-transformed, as necessary. Mean separation used transformed data, but the original data presented for clarity.

3. Results and discussion

3.1. Bell pepper

There were no differences among soil treatments in the number of root galls found on 'Camelot' pepper; a cultivar susceptible to *M. incognita*, in 1998, though all treatments had fewer root galls than the nontreated control (Table 2). Similarly, all treatments to 'Camelot' resulted in fewer root galls than the nontreated control in 1999, however methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) also had lower root-gall indices than fenamiphos + metham and 1,3-D + C35 (drip) (Table 3). There were no differences among treatments or the nontreated control in root-gall indices for 'Charleston Belle' pepper, a cultivar resistant to *M. incognita*, in 1998 or 1999 (Tables 2 and 3).

Differences in nematode populations in the soil could not be detected in 1998 (data not shown), however there were differences among treatments in 1999. Soil samples collected within the row of 'Camelot' pepper indicated that all soil treatments suppressed *M. incognita* populations relative to the nontreated control (Table 3). All treatments, except methyl bromide, had lower *M. incognita* populations than the nontreated control in the 'Charleston Belle' pepper. However, the number of *M. incognita* recovered from the nontreated soil of 'Charleston Belle' pepper was approximately one-ninth of the population recovered from the nontreated soil of 'Camelot' pepper.

Both bell pepper cultivars had low populations of *Paratrichodorus minor* (Colbran) Siddiqi (stubby-root nematode) in the nontreated control in 1999 (Table 3). Higher populations were found in the fenamiphos + metham treatments in both pepper cultivars and in 'Camelot' pepper methyl bromide and 1,3-D + C35 (chisel) treatments than in the nontreated control. Densities of a third nematode species, *Helicotylenchus dihystera* (Cobb) Sher. (spiral nematode), were suppressed by all treatments relative to the nontreated control, with the exception of fenamiphos + metham in the soil of the 'Charleston Belle' pepper. Previous research in a container system indicated that on a molar basis methyl iodide was more efficacious than methyl bromide against three plant-parasitic nematodes, including *M. incognita* (Becker et al., 1998). With the exception of the number of *Paratrichodorus minor* recovered from soil in which 'Camelot' pepper was grown (Table 3), differences in nematode response between methyl bromide and methyl iodide treatments could not be detected.

Purple nutsedge pierced the polyethylene mulch barrier and became the principle weed in these studies. At the conclusion of the season in 1998, only the methyl bromide and 1,3-D + C35 (chisel) treatments had lower purple nutsedge shoot densities piercing the polyethylene mulch relative to the nontreated control (Table 2). These treatments, in addition to methyl iodide, suppressed

Table 2
The effect of soil treatment and crop cultivar on pest populations in pepper in 1998*

Treatment	Root-gall index ^a		Weed densities		
	'Camelot'	'Charleston Belle'	Through polyethylene	Through crop hole	
			Purple nutsedge ^c	Purple nutsedge	Other weeds ^d
no. per plot					
1 1,3-D (drip)	1.13 b	1.06 a	23 ab	5 ab	40 a
2 1,3-D + C35 (chisel)	1.13 b	1.00 a	2 b	1 ab	3 c
3 1,3-D + C35 (drip)	1.19 b	1.19 a	40 ab	8 ab	36 a
4 Methyl bromide	1.31 b	1.13 a	0 b	0 b	3 c
5 Methyl iodide	1.50 b	1.19 a	12 ab	1 ab	16 b
6 Nontreated control	2.31 a	1.06 a	64 a	10 a	45 a

*Treatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^b*Meloidogyne incognita* (southern root knot nematode) root-gall index was rated on a scale of 1-5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

^cPurple nutsedge (*Cyperus rotundus* L.).

^dOther weeds included bermudagrass [*Cynodon dactylon* (L.) Pers.], cutleaf evening primrose (*Oenothera laciniosa* Hill), Florida beggarweed [*Desmodium illinoense* (Sw.) DC.], goosegrass [*Eleusine indica* (L.) Gaertn.], pink purslane (*Portulaca pilosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), smallflower morningglory [*Jakemonia tamnifolia* (L.) Griseb.], and Texas panicum (*Panicum texanum* Buckl.).

Table 3
The effect of soil applied treatments on nematode populations and incidence of root galling in pepper in 1999*

Treatment	<i>Meloidogyne incognita</i> ^b		<i>Paratrichodorus minor</i>		<i>Helicotylenchus dihystra</i>		Root-gall index ^c	
	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'
	no. per 150 cm ³ of soil							
1,3-D + C35 (chisel)	9 b	4 b	74 ab	45 ab	0 b	0 b	1.0 c	1.0
1,3-D + C35 (drip)	108 b	15 b	40 b-d	51 ab	0 b	3 b	1.3 b	1.0
Fenamiphos + metham	219 b	4 b	53 bc	71 a	4 b	9 ab	1.3 b	1.0
Methyl bromide	5 b	54 ab	100 a	49 ab	0 b	3 b	1.0 c	1.0
Methyl iodide	4 b	3 b	33 cd	34 ab	0 b	0 b	1.0 c	1.0
Nontreated control	960 a	109 a	10 d	29 b	38 a	23 a	1.7 a	1.0

*Treatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^b*Meloidogyne incognita* (southern root knot nematode), *Paratrichodorus minor* (stubby-root nematode), *Helicotylenchus dihystra* (spiral nematode).

^c*Meloidogyne incognita* root-gall index was rated on a scale of 1-5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

purple nutsedge emergence through the polyethylene mulch in the early season of 1999 (Fig. 1). However, methyl iodide and 1,3-D + C35 (chisel) only suppressed purple nutsedge emergence and growth early in the season; by the conclusion of the season in 1999, only methyl bromide had lower purple nutsedge shoot densities than the nontreated control. These results indicate that in terms of nutsedge control, an effective replacement for methyl bromide has not yet been identified. However, some of these treatments may be a component of a future nutsedge management system.

Weeds also emerged through the holes in the polyethylene cut for the crop transplants. Compared to the nontreated control, only methyl bromide reduced the number of purple nutsedge that emerged through the crop holes (Table 2). Other weeds were suppressed, relative to the nontreated control, by methyl bromide, methyl iodide and 1,3-D + C35 (chisel) in 1998 (Table 2) and by all treatments in 1999 (data not shown). The number of weeds emerging through the crop holes in the polyethylene was 55 and 20 plants in the nontreated plots in 1998 and 1999, respectively. However, the total area of

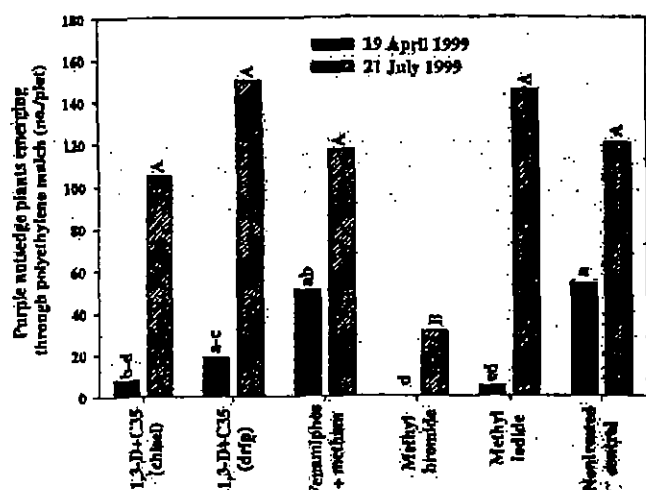


Fig. 1. The effect of soil applied treatments on purple nutsedge densities in pepper in 1999. Treatment means were separated using Fisher's Protected LSD at an alpha level of 0.05. Data were square root transformed prior to analysis and treatment means separated in this form, but presented in their original form in this figure. Treatment means from the early rating data were separated using lowercase letters, while those from the later data were separated using capital letters.

bare soil exposed in each bed by the holes cut into the polyethylene was less than 1.3% ($< 0.25 \text{ m}^2$) of the total area of each bed. Without the polyethylene mulch covering the majority of the bed, it is likely that weed densities would have been much higher and would have greatly affected crop production. While polyethylene mulch can be used to suppress weeds that are unable to penetrate the layer, it can also be an important management tool for nutsedges. Research has indicated that various polyethylene mulches suppressed nutsedge shoot emergence, tuber viability, and altered the competitive relation between nutsedge and crop (Chase et al., 1998; Majek and Neary, 1991; Patterson, 1998).

Pepper plants of both cultivars began to wilt and die in approximately three to four weeks after transplanting in 1998 with a differential mortality rate among treatments. The major pathogenic fungi isolated from the roots of dying plants were *Pythium* spp. [primarily *P. aphenidermatum* Edson (Fitzp.)]. The nontreated control, 1,3-D (drip), and 1,3-D + C35 (drip) treatments had the most wilted plants with no differences between bell pepper cultivars (Table 4). Methyl iodide, methyl bromide, and 1,3-D + C35 (chisel) treatments reduced the number of wilted plants. Differences in plant wilting among treatments could not be detected in 1999. Total fungi isolated from soil were lower in all treated plots relative to the nontreated control, with the exception of methyl iodide, which had almost twice as many colony forming units of fungi as any other treatment (Table 5). This same trend was observed with *Penicillium* spp. and *Paecilomyces* spp. Methyl bromide had the lowest total number of fungi

Table 4
Pepper plant health and cumulative crop yield in 1998

Treatment	Wilted plants ^{a,b}		Crop yield ^a	
	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'
	%		kg per plot	
1,3-D (drip)	78 a	88 a	1.94 c	0.40 c
1,3-D + C35 (chisel)	12 d	32 b	11.7 a	6.35 b
1,3-D + C35 (drip)	63 ab	78 a	2.19 c	0.48 c
Methyl bromide	22 cd	32 b	7.81 b	10.46 a
Methyl iodide	42 bc	37 b	2.86 c	3.16 c
Nontreated control	81 a	94 a	0.54 c	0.45 c

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^bPepper plants of both *Meloidogyne incognita*-susceptible ('Camelot') and *M. incognita*-resistant ('Charleston Belle') varieties began to wilt and die in approximately three to four weeks after transplanting in 1998 with a differential mortality rate among treatments. Major pathogenic fungi isolated from the roots of dying plants were *Pythium* spp. (primarily *P. aphenidermatum*).

and was the only treatment that was consistently effective in suppressing fungi across all species evaluated (*Pythium* spp., *Fusarium solani*, total *Fusarium* spp., *Trichoderma* spp., *Penicillium* spp., and *Paecilomyces* spp.). Fenamiphos + metham controlled some of the pathogenic fungi, but did not reduce *Fusarium* spp. Both 1,3-D + C35 (chisel) and (drip) did not reduce populations of the beneficial *Trichoderma* spp. and were effective in reducing *Penicillium* spp., *Paecilomyces* spp. and total fungi relative to the nontreated control. However, both treatments had similar populations of *Fusarium solani* and *Pythium* spp. to that of the nontreated control (Table 5).

Fruit yield (kg per plot) of pepper in 1998 was highest with 1,3-D + C35 (chisel) and methyl bromide for 'Camelot' and 'Charleston Belle' cultivars, respectively (Table 4). Differences in fruit yield could not be detected among the nontreated control, methyl iodide, 1,3-D + C35 (drip), and 1,3-D (drip) in either cultivar in 1998. Lower yields from these treatments were probably related to the *Pythium* spp. that caused significant plant wilting and mortality. In 1999, only 1,3-D + C35 (chisel) increased yield above the nontreated control for both 'Charleston Belle' and 'Camelot' cultivars. Fenamiphos + metham and methyl bromide treatments had higher fruit yields than the nontreated controls for 'Charleston Belle' pepper (Fig. 2). However, there were similar fruit yields among 1,3-D + C35 (chisel), 1,3-D + C35 (drip), and methyl bromide for both cultivars, and fenamiphos + metham for 'Charleston Belle', and methyl iodide for 'Camelot' pepper.

Table 5
The effect of soil applied treatments on fungal populations in pepper^a

Treatment	<i>Pythium</i> spp.	<i>Fusarium solani</i>	Total <i>Fusarium</i> spp.	<i>Trichoderma</i> spp. (×1000)	<i>Penicillium</i> spp. + <i>Paecilomyces</i> spp. (×1000)	Total fungi (×1000)
				CFU ^b		
1,3-D + C35 (chisel)	29 cd	420 b	760 bc	75.1 a	0 d	93.5 c
1,3-D + C35 (drip)	109 ab	370 b	880 b	77.5 a	0 d	111.4 b
Fenamiphos + metham	63 bc	1750 b	2450 a	5.3 b	8.2 bc	66.4 c
Methyl bromide	1 d	20 c	120 c	1.5 b	4.4 c	36.3 d
Methyl iodide	257 a	8610 a	9970 a	22.3 a	25.7 ab	213.7 a
Nontreated control	237 ab	970 ab	2400 a	24.2 a	76.7 a	304.9 a

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^bNumber of colony forming units (CFU) per gram of oven-dry soil.

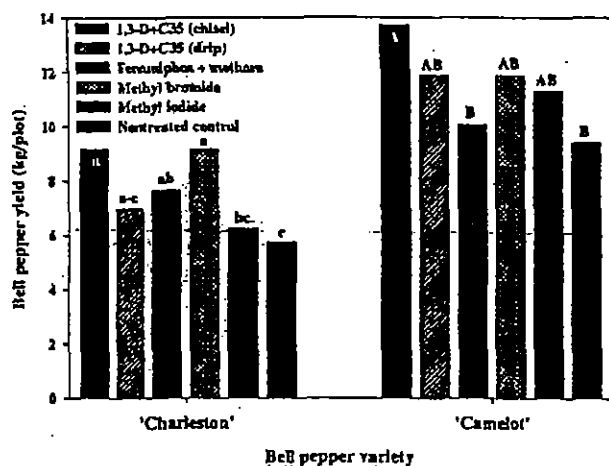


Fig. 2. The effect of soil treatment on pepper yield for both *Meloidogyne incognita*-resistant and *M. incognita*-susceptible pepper varieties in 1999. Treatment means were separated using Fisher's Protected LSD at an alpha level of 0.05; lower case letters were used to differentiate treatments in *M. incognita*-resistant pepper, while capital letters were used to separate treatment means in *M. incognita*-susceptible pepper.

3.2. Squash

Relative to all other treatments, a higher population of *M. incognita* was detected following the first crop treatment of 1,3-D + C35 (chisel) in 'Camelot' pepper that were left nontreated prior to the squash crop in 1998 (Table 6). Differences in *M. incognita* populations could not be detected among all other treatments and the nontreated control for the first crop followed by nontreated control for the second crop in 1998. There were significant differences in number of *M. incognita* recovered from soil among first crop soil treatments in

1999 (Table 7). Treatments of methyl bromide, 1,3-D + C35 (chisel), and fenamiphos + metham applied prior to the first crop resulted in lower *M. incognita* populations than in the nontreated control. There was a significant second crop treatment by pepper cultivar interaction in 1999, which indicated that a treatment of metham applied through the irrigation tubing following the susceptible cultivar of pepper ('Camelot') had lower *M. incognita* soil populations than did the same cultivar that did not have any application for the control of nematodes prior to the second crop. In plots that had resistant pepper cultivar as the first crop, there were no differences in *M. incognita* soil populations between second crop treatments of metham and nontreated plots (Table 7). Previous research indicated that cucumber following nematode-resistant tomato had lower soil populations of *M. incognita* than those following nematode-susceptible tomato (Hanna et al., 1994). Clearly pest resistant cultivars, where possible, should be one component of a methyl bromide alternative system.

Root-gall indices of squash in 1998 indicated no differences among first crop or second crop treatments when squash was planted following the nematode-resistant pepper cultivar ('Charleston Belle') (Table 6). However, there were differences among treatments following the nematode-susceptible cultivar ('Camelot') in 1998. Squash in plots that were treated with methyl bromide (first crop) followed by a nontreated control (second crop) or 1,3-D + C35 (chisel) (first crop) followed by nontreated control (second crop) both had higher root-gall indices than the nontreated control for the first crop followed by nontreated control for the second crop treatment. However, when an application of metham was applied through the drip irrigation tubing prior to the

Table 6

The effect of first and second crop treatments on *Meloidogyne incognita* (southern root knot nematode) population and root-gall indices in the second crop of squash in 1998^a

First crop Treatment	Second crop Treatment	<i>Meloidogyne incognita</i>		Root-gall index ^c	
		'Camelot' ^b	'Charleston Belle'	'Camelot'	'Charleston Belle'
		no. per 150 cm ³ of soil			
1,3-D (drip)	Metham	5 b	0 b	1.1 c	1.1 c
	Nontreated control	10 b	8 b	1.0 c	1.0 c
1,3-D + C35 (chisel)	Metham	3 b	3 b	1.0 c	1.0 c
	Nontreated control	50 a	8 b	2.2 a	1.3 bc
1,3-D + C35 (drip)	Metham	0 b	0 b	1.1 c	1.0 c
	Nontreated control	10 b	3 b	1.2 bc	1.1 c
Methyl bromide	Metham	5 b	3 b	1.2 c	1.0 c
	Nontreated control	0 b	0 b	1.8 ab	1.0 c
Methyl iodide	Metham	0 b	0 b	1.2 bc	1.0 c
	Nontreated control	0 b	0 b	1.2 bc	1.0 c
Nontreated control	Metham	3 b	0 b	1.0 c	1.0 c
	Nontreated control	8 b	8 b	1.1 c	1.0 c

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter could not be detected.

^bFirst crop treatments included a *M. incognita*-susceptible pepper ('Camelot') and a *M. incognita*-resistant pepper ('Charleston Belle').

^c*Meloidogyne incognita* root-gall index was rated on a scale of 1–5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

Table 7

The effect first crop (pepper) treatments on second crop (squash) nematode population, root-gall index, and crop response in 1999^a

Treatment	<i>Meloidogyne incognita</i> (no./150 cm ³ soil)	Root-gall index ^b	Plant vigor rating ^c	Fruit weight (kg/plot)	Marketable Fruit ^d (%)
1,3-D + C35 (chisel)	9 bc	1.1 b	4.1 b	1.1 b	60 ab
1,3-D + C35 (drip)	26 a–c	1.6 a	5.1 ab	1.0 b	52 b
Fenamiphos + metham	10 bc	1.5 ab	4.4 b	0.9 b	48 b
Methyl bromide	1 c	1.0 b	6.5 a	2.7 a	74 a
Methyl iodide	35 a–c	1.1 b	4.6 ab	1.6 b	74 a
Nontreated control	84 a	1.8 a	4.4 b	1.0 b	55 ab
Interactions					
Metham – 'Camelot'	1 b	1.3	4.9	1.5	58
Metham – 'Charleston Belle'	12 ab	1.2	4.9	1.6	65
Nontreated control – 'Camelot'	73 a	1.7	4.8	1.2	61
Nontreated control – 'Charleston Belle'	24 ab	1.2	4.8	1.2	60

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column above the centerline or in interaction below the center line, could not be detected.

^b*Meloidogyne incognita* root-gall index was rated on a scale of 1–5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

^cPlant vigor was rated on a scale of 1 (least vigorous) to 10 (most vigorous).

^dMarketable fruit were the percentage of the total harvested squash that were not graded as a cull.

second crop, the root-gall indices in all first crop treatments did not exceed a value of 1.2 in 1998 (Table 6).

Root-galls indices in squash in 1999 caused by *M. incognita* indicated that there was no effect of the second crop treatments. However, there was an effect of the first crop soil treatments on the second crop root-gall indices (Table 7). Methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) had lower root-gall indices than the

nontreated control. Fenamiphos + metham and 1,3-D + C35 (drip) were not different from the nontreated control. While there was no significant interaction among pepper cultivars and second crop applications in root gall ratings, the trend in root-gall indices reflected the numbers of *M. incognita* in the soil (Table 7).

Squash plant vigor was influenced by the first crop treatments and was greatest in methyl bromide treated

plots (Table 7). All other treatments were not different from the nontreated control. Differences in plant vigor could not be detected among second crop treatments nor related to the cultivar of the previous pepper crop. Higher plant vigor ratings from the methyl bromide treatment resulted in higher squash yields relative to all other treatments in 1999 (Table 7). The nontreated control was similar in yield to all other nonmethyl bromide treatments. Differences in crop yield in 1998 among treatments could not be detected (data not shown). Approximately 74% of the harvested fruit were marketable from the methyl bromide and methyl iodide plots in 1999, but this was not different from the nontreated control (Table 7). These values were higher than those from plots treated with 1,3-D + C35 (drip) and fenamiphos + metham. Second crop treatments did not have any detectable effect on plant vigor rating, fruit weight, or the percent of marketable fruit (Table 7).

Nutsedges were identified as the most troublesome weeds of vegetable crops in Georgia (Webster and MacDonald, unpublished). While purple nutsedge was a problem during the first crop, the presence of this weed species was erratic in the second crop. Differences in purple nutsedge densities among treatments could not be detected in the second crop in 1998 or 1999, nor could any trends within the data be observed (data not shown). Treatment of the plots between the first and second crop with glyphosate probably had a significant influence on the reduction of purple nutsedge shoots in the second crop. With the exception of the methyl bromide treatments, all plots had purple nutsedge shoot densities greater than 5/m² emerged through the polyethylene and measured 25-61 cm in height at the time of glyphosate treatment. This application of glyphosate reduced the purple nutsedge shoot population in the second crop 82-99%, regardless of the second crop treatment. The nonselective herbicide paraquat is often used to eliminate weedy vegetation between vegetable crops, primarily because of its low price, quick action, and broad spectrum of weed control. However, this will often only provide contact burn of exposed purple nutsedge foliage and will not control any underground tubers. Glyphosate was reported to control nutsedge tubers that were attached to treated foliage (Doll and Piedrahita, 1982). These researchers found that new shoots of purple nutsedge that emerged following glyphosate applications originated from dormant tubers. Based on the reduced nutsedge populations observed in the current study, an application of glyphosate between crops is recommended to assist in weed control in a plasticulture system. However, results of this study indicate that an effective replacement for methyl bromide for weed control within the crop has not yet been found.

Many pests were controlled effectively with methyl bromide (nematodes, soil-borne plant pathogenic fungi, soil-borne insects, and weeds), however, the potential

methyl bromide-replacements investigated in this study do not have the broad-spectrum pest control of methyl bromide. Following the elimination of methyl bromide, pest management in vegetable crops will need to further rely on the principles of integrated pest management (IPM). Correct identification of pests and implementation of appropriate control measures have become increasingly important in the effective management of pests in systems that previously relied on methyl bromide. Instead of a limited number of pest control tactics, new pest management systems will need to rely on multiple components aimed at controlling weeds, nematodes, and soilborne plant pathogenic fungi and insects. These systems in the future may also include a broader arsenal of herbicides for several crops with minor hectareage due to the efforts of the US Interregional Research Project 4 (IR-4) (<http://pestdata.ncsu.edu/ir-4/>), which is a collaborative effort between the State Agricultural Experiment Stations and the USDA-Agricultural Research Service. In addition, integration of cultural practices such as crop rotation (McSorley, 1996), pest resistant cultivars (Thies and Fery, 1997), stale seed bed techniques (Johnson and Mullinix, 1998), precision fertilization and watering, the use of organic amendments (Blok et al., 2000; Gardiner et al., 1999; Kirkengaard and Sarwar, 1999) and the choice of polyethylene mulch (Chase et al., 1998; Patterson, 1998) may also improve pest control and should be investigated across multiple disciplines in future studies.

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For EPA Use Only
ID#**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D (dripline)

[Insert Alternative]

Study: Methyl bromide alternatives in a bell pepper-squash rotation

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted	<u>X</u>
1b. Township caps	<u> </u>
1c. Alternative not acceptable in consuming country	<u> </u>
1d. Other (Please describe)	<u> </u>

Possible use in pepper, cucurbit crops, tomato and strawberry.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Webster, Csinos, Johnson, Dowler, Sumner, Fery

3. Publication and Date of Publication Crop Protection, 2001

4. Location of research study Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

1,3-D

6. Was crop yield measured in the study? Yes _____ No X

7. Describe the effectiveness of the alternative in controlling pests in the study.

Not effective

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

This alternative would not be used for purple nutsedge control because it is not effective.

Alternative: 1,3-D (dripline)Study: Webster, Calnos, Johnson, Dowler, Sumner, and Fary, 2001For EPA Use Only
ID#

Research Summary Table

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. at per area)	Pest 1: Purple Nutsedge Density						Pest 2: Other Weeds in Study Density						Pepper Yield (kg/plot)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
7	nontreated		harvest	64					harvest	45					0.45 0.54
2	methyl bromide	440 kg/ha	harvest	0					harvest	3					10.46 7.81
4	1,3-D (drip)	136 kg ai/ha	harvest	23					harvest	40					0.40 1.99

Comments: 1.8 by 7.6 m plot; yield data = "Charleston Belle" | "Camelot".

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Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

1,3-D (dripline)

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural-users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Pepper	grade, time, market	boxes (25 pounds)	98.00	\$ 8.25	
			20.00	\$ 8.25	
			118 / 2 = 59	\$ 8.25	\$ 486.75
				Total Revenue	\$ 486.75

Comments:

03-0041

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

ID#

1,3-D (dripline)

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item.	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No change

03-0041



Methyl bromide alternatives in a bell pepper–squash rotation

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Abstract

Field studies were conducted to evaluate potential methyl bromide alternatives against multiple pests in a bell pepper (*Capsicum annuum* L.) – squash (*Cucurbita pepo* L.) cropping sequence. Early in the growing season, the most effective treatments in suppressing purple nutsedge (*Cyperus rotundus* L.) emergence through the polyethylene mulch were methyl bromide, methyl iodide, and chisel-injected 1,3-dichloropropene plus chloropicrin [1,3-D + C35 (chisel)]. However by the end of the season in 1999, only methyl bromide treatment had less purple nutsedge emerging through the polyethylene than the nontreated control. Each soil-applied treatment resulted in nematode-susceptible pepper plants with lower root-gall indices [*Meloidogyne* spp. (root knot nematode)] than the nontreated control, while there were no differences among treatments with the nematode-resistant pepper cultivar. Total fungi isolated from soil was lower in all treated plots relative to the nontreated control, with the exception of methyl iodide. However, methyl bromide was the only treatment that was consistently effective against *Pythium* spp. and *Fusarium* spp. A treatment of metham prior to planting squash was beneficial in reducing root-gall indices in plots treated with 1,3-D + C35 (chisel) and methyl bromide prior to the pepper crop. Methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) applied before pepper resulted in squash with lower root-gall indices than the nontreated control. Glyphosate applied between the first and second crop eliminated exposed weed foliage through the polyethylene mulch, possibly muting the effects of the second crop treatment on weed densities. Results of this study indicate that there are some potential methyl bromide alternatives available to growers for use in pest control, however there does not appear to be one broad-spectrum pesticide that will replace methyl bromide. Also, an effective control for nutsedge species within the pepper–squash cropping system is still elusive. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: *Cyperus rotundus*; *Fusarium* spp; *Meloidogyne incognita*; Methyl bromide; *Pythium* spp; Metham; Methyl iodide; 1,3-dichloropropene

1. Introduction

Methyl bromide is an effective soil fumigant used extensively prior to planting many vegetable and fruit crops to control a broad-spectrum of pests that include nematodes, soilborne plant pathogenic fungi, soilborne insects, and weeds. Methyl bromide has been used since the 1950s to eliminate pest problems in many minor-use crops. Many of these crops have a limited number of pesticide alternatives due to the high cost associated with the registration of a pesticide. This high cost coupled with the relatively low numbers of hectares of these crops

makes most pesticide manufacturers reluctant to register pesticides for minor-use crops. While this has been an important issue surrounding minor-use crops, it has been tempered by the availability of methyl bromide and its biocide activities. However, methyl bromide was listed as a Class I ozone depleting substance by the US Environmental Protection Agency in 1993 and its use is scheduled to be halted by the year 2005. While methyl bromide is used for post-harvest pest control of stored products and for pest control of buildings and other structures, it is estimated that 85% of methyl bromide is used in agriculture as a preplant soil fumigant for high value vegetable and agronomic crops (Julian et al., 1998). With the impending elimination of this valuable compound, growers will need viable alternatives to manage a wide range of pests.

Previous research has identified several potential pest management alternatives for methyl bromide in various

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cropping systems. Methyl iodide has been proposed as a methyl bromide replacement without the suspected depletion of the stratospheric ozone layer that is attributed to methyl bromide (Ohr et al., 1996). Becker et al. (1998) found that applications of methyl iodide at 168 kg/ha eliminated *Meloidogyne incognita* (Kofoed & White) Chitwood (southern root knot nematode) juveniles eight days after treatment and that root galling on lima beans [*Phaseolus lunatus* L. cv. Henderson] was suppressed to less than 1% at two months following treatment. Methyl iodide applied at rates as low as 28 kg/ha reduced populations of *M. incognita* to less than 3/100 cm³ of soil at five weeks after treatment in tomato (Noling and Gilreath, 1995). However, by 11 weeks after treatment the severity of root galls on tomato plants in the methyl iodide treatments was not different from the nontreated control. Laboratory studies indicated that methyl iodide was generally more biologically active on velvetleaf (*Abutilon theophrasti* Medik.) and Italian ryegrass (*Lolium multiflorum* Lam.) seeds than methyl bromide and optimum efficacy was related to soil hydration (Zhang et al., 1998).

Other potential methyl bromide replacements include metham, 1,3-dichloropropene, chloropicrin, and various combinations of these compounds. When applied in the fall of the year to nursery beds of bell pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentus* Miller), and tobacco (*Nicotiana glauca* L.), metham efficacy was similar to methyl bromide plus chloropicrin (98:2) in 76 of 79 tested parameters which included crop vigor, winter annual weed control, soilborne fungal populations, nematode soil populations and nematode injury ratings (Csinos et al., 2000). In a transplant production system, the combination of metham + 1,3-dichloropropene + chloropicrin was similar to methyl bromide in control of weeds [yellow nutsedge (*Cyperus esculentus* L.), Florida pusley (*Richardia scabra* L.), and winter annual weed species], fungi (*Pythium* spp., *Rhizoctonia solani* Kühn), and crop response (stand count, crop vigor rating, and crop height) (Csinos et al., 1997). Other research found that plots treated with either 1,3-dichloropropene + chloropicrin or metham had lower tomato fruit yield, inferior control of yellow nutsedge, and higher fungal populations compared to the methyl bromide treated plots (Locascio et al., 1997).

The objective of this study was to determine the effects of soil chemical treatments on nematodes, weeds, soilborne plant pathogenic fungi, and crop response in a bell pepper-squash (*Cucurbita pepo* L.) cropping sequence in a plasticulture production system. In addition, bell pepper cultivars resistant or susceptible to *M. incognita* were used in the sequence across all soil treatments in order to evaluate the residual effects of the resistant crops in suppressing nematode populations in the subsequent *M. incognita*-susceptible squash crop.

2. Materials and methods

2.1. General

Field studies were conducted in 1998 and 1999 at the Coastal Plain Experiment Station in Tifton, GA. The soil was a Dothan loamy sand (fine-loamy, siliceous thermic Plinthic Paleudults: 93% sand, 4% silt, 3% clay) with 0.5% organic matter and a soil pH of 6.0 to 6.5. The area was naturally infested with *Meloidogyne incognita* [(Kofoed & White), Chitwood race 1, southern root knot nematode], *Pythium* spp., *Fusarium* spp., and purple nutsedge (*Cyperus rotundus* L.). The land was previously planted to cowpea [*Vigna unguiculata* (L.) Walp. cv. Pinkeye Purplehull] as a summer cover crop and hairy vetch (*Vicia villosa* Roth) as a winter cover crop to increase native densities of *M. incognita*.

The soil was disk harrowed and moldboard plowed 25–30 cm deep. Dolomitic limestone (2240 kg/ha) and 5–10–15 fertilizer (560 kg/ha) were broadcast and incorporated to a depth of 8–10 cm with a tractor-mounted rototiller. Single beds (76 cm wide, 7.6 m long, and 15 cm high) were established with a bed shaper. A single drip irrigation tube with emitters spaced 30 cm apart with a flow rate of 30 ml/min/30 m was placed in the center of the bed under the polyethylene mulch for application of water, fertilizer, and some fumigants. Black 32 µm-thick (1.25 mil) polyethylene mulch covered each bed immediately following chisel injected and soil fumigant applications. Designated treatments were applied through the drip irrigation system the following day.

Seedlings for transplants were grown in a greenhouse in plastic trays (6.4 cm × 34.3 cm × 67.3 cm) containing 128 cells (3.8 cm diameter by 6.4 cm deep). Cells were filled with a dry mixture of vermiculite and sphagnum peat moss (35:65). Trays were placed in a vat of water containing 20–20–20 fertilizer at 0.6 g/l of water. After 12 h, the medium in each cell contained the maximum moisture for seeding. The medium in each cell was compressed to a depth of 1.3 cm from the bottom of the tray. One seed was placed in each cell and covered with dry medium. Within 8 h the dry medium contained adequate moisture for seed germination. Trays remained in vats until after seed germination and were monitored for adequate moisture. To begin the acclimation of seedlings to field conditions, plants were removed from the greenhouse and placed in a field environment several days prior to transplanting.

2.2. Bell pepper

Treatments were arranged as a split-split-plot, with soil treatments applied prior to bell pepper (first crop) as the main plots, chemigated soil treatments applied through irrigation tubing prior to squash (second crop) as subplots (described later in detail in the squash

Table 1
Main and subplot treatments applied to pepper and squash crops

	Application method	Rate	Date applied
Main plot (first crop treatments)^a			
Fenamiphos + metham	Broadcast to soil surface ^b + chemigated through drip tape ^c	6.7 kg ai/ha + 240 kg ai/ha	30 March 1998; 31 March 1999
Methyl bromide	Fumigated	440 kg ai/ha	13 April 1998; 30 March 1999
Methyl iodide	Chemigated through drip tape ^c	440 kg ai/ha	13 April 1998; 1 April 1999
1,3-dichloropropene (1,3-D)	Chemigated through drip tape ^c	136 kg ai/ha	13 April 1998
1,3-dichloropropene + chloropicrin [1,3-D + C35 (chisel)]	Chisel injected	146 kg ai/ha + 83 kg ai/ha	13 April 1998; 30 March 1999
1,3-dichloropropene + chloropicrin [1,3-D + C35 (drip)]	Chemigated through drip tape ^c	146 kg ai/ha + 83 kg ai/ha	13 April 1998; 31 March 1999
Nontreated control	—	—	—
Sub-plot (second crop treatments)^d			
Metham	Chemigated through drip tape ^c	240 kg ai/ha	21 July 1998; 26 July 1999
Nontreated control	—	—	—

^aMain plots were 3.6 m × 7.6 m and treatments applied prior to pepper crop.

^bGranular fenamiphos was applied to the soil surface and shallowly incorporated.

^cPlots were chemigated for 60 min using a pump that delivered 126 ml/min. Water was added to each treatment to a total volume of 7500 ml. Following each 60 min treatment application, the lines were flushed with water for 30 min into the treated plots prior to application of the next treatment. This system was equipped with pressure regulators that maintained a consistent 83 kPa through the irrigation tubing.

^dSub-plots were 1.8 m × 7.6 m, each main plot treatment was divided to receive subplot treatments that were applied prior to squash crop.

section), and nematode-resistant and nematode-susceptible bell pepper cultivar were the sub-subplots (Table 1). Main plots were 3.6 m wide and 7.6 m long and consisted of two subplots each 1.8 m wide and 7.6 m long. The subplots were planted to two rows of bell pepper, one of each cultivar, which constituted the sub-subplot.

To allow for aeration prior to crop transplanting, two rows of holes 8 cm in diameter and spaced 30 cm apart were cut into the polyethylene mulch of each bed at 10 and 14 days after the methyl bromide treatment in 1998 and 1999, respectively. Five days after holes were cut in the polyethylene, a single greenhouse-grown pepper plant was planted in each hole with one row of *M. incognita*-resistant 'Charleston Belle' and one row of *M. incognita*-susceptible 'Camelot' pepper per bed on 27 April 1998 and 16 April 1999.

All pepper plots were sprayed on a 7–10-day schedule with 2 kg ai/ha maneb (Manex, Griffin LLC, Valdosta, GA 31601) and 1.3 kg ai/ha copper hydroxide (Kocide, Griffin LLC, Valdosta, GA 31601) in a water volume of 187 l/ha for foliar disease control. All plots received liquid fertilizer injected through the drip irrigation system once a week for a total of 130 kg/ha of nitrogen, 48 kg/ha of P₂O₅, 27 kg/ha K₂O, and 1 kg/ha boron.

Twenty soil cores (2.5 cm-diameter, 25 cm-depth) for nematode assay were collected from each row of pepper at monthly intervals from March through July in 1998 and April through July in 1999. The samples from each row within a plot were pooled and a 150 cm³ subsample was processed by centrifugal flotation method to separ-

ate nematodes from the soil (Jenkins, 1964). A 100 cm³ subsample was assayed for populations of *Pythium* spp. (P₅ ARP media) (Jeffers and Martin, 1986), *Fusarium solani* (Mart.) Sacc. and *Fusarium oxysporum* Schlecht. Fr. (modified PCNB) (Papavizas, 1967), *Aspergillus* spp., *Trichoderma* spp., *Penicillium* spp., and *Paecilomyces* spp. (OAES media) (Williams and Schmitthenner, 1960). Roots of five pepper plants from each plot were dug, washed in tap water, blotted dry with paper towels, and rated for root galls caused by *M. incognita* after final harvest. A scale ranging from 1 to 5 was used where 1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% of the root system with galls.

The total number of living plants per plot was recorded in May of each year. Some plants began to show symptoms of wilting even in the presence of adequate soil moisture 4–6 weeks after planting in 1998. The number of wilted and healthy plants was recorded on 10 June 1998 and 10 July 1998.

All fruit were hand-harvested, separated into marketable and cull, counted, and weighed in late June and early July. After the final harvest, all weeds growing in the hole in the polyethylene where the bell peppers or squash plants were planted and those penetrating through the polyethylene mulch were identified and counted. Due to the diversity of weeds that emerged through the crop holes, weeds were divided into two categories: purple nutsedge and other weeds. The other weeds included bermudagrass [*Cynodon dactylon* (L.) Pers.], cutleaf

eveningprimrose (*Oenothera laciniata* Hill), Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], goosegrass [*Eleusine indica* (L.) Gaertn.], pink purslane (*Portulaca pilosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), smallflower morningglory [*Jaquemontia tamnifolia* (L.) Griseb.], and Texas panicum (*Panicum texanum* Buckl.). After weeds were counted and identified, all pepper plants were cut at the soil surface and removed from the plots. All plots were sprayed with 2.2 kg ai/ha glyphosate to eliminate all existing weeds prior to applying treatments for the second crop.

2.3. Squash

Main plots (first crop soil treatments) were split into two treatments for the second crop. Subplots included a nontreated control and an application of metham chemigated through the irrigation tubing on 21 July 1998 and 26 July 1999 (Table 1). Squash cultivar 'Dixie' seedlings were produced in the greenhouse using the methods previously described. Seedlings were large enough to transplant 12–15 days after seeding and were transplanted in the holes between the original pepper plants on 5 August 1998 and 10 August 1999.

All plots of squash received liquid fertilizer through the drip irrigation system at three to four day intervals totaling 130 kg/ha of nitrogen, 57 kg/ha of P_2O_5 and 41 kg/ha K_2O over 12 applications. All squash plots were sprayed with 0.1 kg ai/ha mefenoxam and 1.6 kg ai/ha chlor-thalonil (Ridomil Gold Bravo, Novartis Crop Protection, Inc., Greensboro, NC 27419) for control of crown and foliar diseases and 0.11 kg ai/ha permethrin (Pounce, FMC Corporation, Agricultural Products Group, Philadelphia, PA 19103) and 4.61 kg ai/ha potassium salts of fatty acids (M-Pede, Mycogen Corporation, San Diego, CA 92121) for insect control on a 7–10 day interval.

Five squash plants were dug from each plot following the last harvest and rated for galls as previously described for pepper. Squash fruit were harvested three times a week for 2–3 weeks. Fruit were graded as either marketable or cull, and the number and weight at each harvest were determined. After the final harvest, weed populations were determined and root galls were rated from five plants as previously described.

2.4. Data analysis

All data were subjected to analysis of variance and means separated using Fisher's Protected LSD Test or Duncan's Multiple Range Test, both at an alpha level of 0.05. Prior to analysis of variance, data on pest populations were square-root-transformed, as necessary. Mean separation used transformed data, but the original data presented for clarity.

3. Results and discussion

3.1. Bell pepper

There were no differences among soil treatments in the number of root galls found on 'Camelot' pepper, a cultivar susceptible to *M. incognita*, in 1998, though all treatments had fewer root galls than the nontreated control (Table 2). Similarly, all treatments to 'Camelot' resulted in fewer root galls than the nontreated control in 1999, however methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) also had lower root-gall indices than fenamiphos + metham and 1,3-D + C35 (drip) (Table 3). There were no differences among treatments or the nontreated control in root-gall indices for 'Charleston Belle' pepper, a cultivar resistant to *M. incognita*, in 1998 or 1999 (Tables 2 and 3).

Differences in nematode populations in the soil could not be detected in 1998 (data not shown), however there were differences among treatments in 1999. Soil samples collected within the row of 'Camelot' pepper indicated that all soil treatments suppressed *M. incognita* populations relative to the nontreated control (Table 3). All treatments, except methyl bromide, had lower *M. incognita* populations than the nontreated control in the 'Charleston Belle' pepper. However, the number of *M. incognita* recovered from the nontreated soil of 'Charleston Belle' pepper was approximately one-ninth of the population recovered from the nontreated soil of 'Camelot' pepper.

Both bell pepper cultivars had low populations of *Paratrichodorus minor* (Colbran) Siddiqi (stubby-root nematode) in the nontreated control in 1999 (Table 3). Higher populations were found in the fenamiphos + metham treatments in both pepper cultivars and in 'Camelot' pepper methyl bromide and 1,3-D + C35 (chisel) treatments than in the nontreated control. Densities of a third nematode species, *Helicotylenchus dihystera* (Cobb) Sher. (spiral nematode), were suppressed by all treatments relative to the nontreated control, with the exception of fenamiphos + metham in the soil of the 'Charleston Belle' pepper. Previous research in a container system indicated that on a molar basis methyl iodide was more efficacious than methyl bromide against three plant-parasitic nematodes, including *M. incognita* (Becker et al., 1998). With the exception of the number of *Paratrichodorus minor* recovered from soil in which 'Camelot' pepper was grown (Table 3), differences in nematode response between methyl bromide and methyl iodide treatments could not be detected.

Purple nutsedge pierced the polyethylene mulch barrier and became the principle weed in these studies. At the conclusion of the season in 1998, only the methyl bromide and 1,3-D + C35 (chisel) treatments had lower purple nutsedge shoot densities piercing the polyethylene mulch relative to the nontreated control (Table 2). These treatments, in addition to methyl iodide, suppressed

Table 2
The effect of soil treatment and crop cultivar on pest populations in pepper in 1998^a

Treatment	Root-gall index ^b		Weed densities		
	'Camelot'	'Charleston Belle'	Through polyethylene	Through crop hole	
			Purple nutsedge ^c	Purple nutsedge	Other weeds ^d
			no. per plot		
1,3-D (drip)	1.13 b	1.06 a	23 ab	5 ab	40 a
1,3-D + C35 (chisel)	1.13 b	1.00 a	2 b	1 ab	3 c
1,3-D + C35 (drip)	1.19 b	1.19 a	40 ab	8 ab	36 a
Methyl bromide	1.31 b	1.13 a	0 b	0 b	3 c
Methyl iodide	1.50 b	1.19 a	12 ab	1 ab	16 b
Nontreated control	2.31 a	1.06 a	64 a	10 a	45 a

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^b*Meloidogyne incognita* (southern root knot nematode) root-gall index was rated on a scale of 1–5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

^cPurple nutsedge (*Cyperus rotundus* L.).

^dOther weeds included bermudagrass [*Cynodon dactylon* (L.) Pers.], cutleaved primrose (*Oenothera lacinata* Hill), Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], goosegrass [*Eleusine indica* (L.) Gaertn.], pink purslane (*Portulaca pilosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), smallflower morningglory [*Jaquemontia tamnifolia* (L.) Griseb.], and Texas panicum (*Panicum texanum* Buckl.).

Table 3
The effect of soil applied treatments on nematode populations and incidence of root galling in pepper in 1999^a

	<i>Meloidogyne incognita</i> ^b		<i>Paratrichodorus minor</i>		<i>Helicotylenchus dihystra</i>		Root-gall index ^c	
Treatment	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'
	no. per 150 cm ³ of soil							
1,3-D + C35 (chisel)	9 b	4 b	74 ab	45 ab	0 b	0 b	1.0 c	1.0
1,3-D + C35 (drip)	108 b	15 b	40 b-d	51 ab	0 b	3 b	1.3 b	1.0
Fenamiphos	219 b	4 b	53 bc	71 a	4 b	9 ab	1.3 b	1.0
+ metham								
Methyl bromide	5 b	54 ab	100 a	49 ab	0 b	3 b	1.0 c	1.0
Methyl iodide	4 b	3 b	33 cd	34 ab	0 b	0 b	1.0 c	1.0
Nontreated control	960 a	109 a	10 d	29 b	38 a	23 a	1.7 a	1.0

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^b*Meloidogyne incognita* (southern root knot nematode), *Paratrichodorus minor* (stubby-root nematode), *Helicotylenchus dihystra* (spiral nematode).

^c*Meloidogyne incognita* root-gall index was rated on a scale of 1–5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

purple nutsedge emergence through the polyethylene mulch in the early season of 1999 (Fig. 1). However, methyl iodide and 1,3-D + C35 (chisel) only suppressed purple nutsedge emergence and growth early in the season; by the conclusion of the season in 1999, only methyl bromide had lower purple nutsedge shoot densities than the nontreated control. These results indicate that in terms of nutsedge control, an effective replacement for methyl bromide has not yet been identified. However, some of these treatments may be a component of a future nutsedge management system.

Weeds also emerged through the holes in the polyethylene cut for the crop transplants. Compared to the nontreated control, only methyl bromide reduced the number of purple nutsedge that emerged through the crop holes (Table 2). Other weeds were suppressed, relative to the nontreated control, by methyl bromide, methyl iodide and 1,3-D + C35 (chisel) in 1998 (Table 2) and by all treatments in 1999 (data not shown). The number of weeds emerging through the crop holes in the polyethylene was 55 and 20 plants in the nontreated plots in 1998 and 1999, respectively. However, the total area of

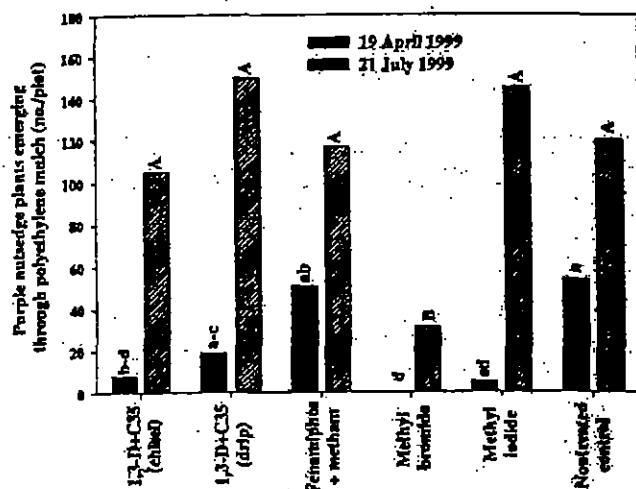


Fig. 1. The effect of soil applied treatments on purple nutsedge densities in pepper in 1999. Treatment means were separated using Fisher's Protected LSD at an alpha level of 0.05. Data were square root transformed prior to analysis and treatment means separated in this form, but presented in their original form in this figure. Treatment means from the early rating data were separated using lowercase letters, while those from the later data were separated using capital letters.

bare soil exposed in each bed by the holes cut into the polyethylene was less than 1.3% ($< 0.25 \text{ m}^2$) of the total area of each bed. Without the polyethylene mulch covering the majority of the bed, it is likely that weed densities would have been much higher and would have greatly affected crop production. While polyethylene mulch can be used to suppress weeds that are unable to penetrate the layer, it can also be an important management tool for nutsedges. Research has indicated that various polyethylene mulches suppressed nutsedge shoot emergence, tuber viability, and altered the competitive relation between nutsedge and crop (Chase et al., 1998; Majek and Neary, 1991; Patterson, 1998).

Pepper plants of both cultivars began to wilt and die in approximately three to four weeks after transplanting in 1998 with a differential mortality rate among treatments. The major pathogenic fungi isolated from the roots of dying plants were *Pythium* spp. [primarily *P. aphenidermatum* Edson (Fitzp.)]. The nontreated control, 1,3-D (drip), and 1,3-D + C35 (drip) treatments had the most wilted plants with no differences between bell pepper cultivars (Table 4). Methyl iodide, methyl bromide, and 1,3-D + C35 (chisel) treatments reduced the number of wilted plants. Differences in plant wilting among treatments could not be detected in 1999. Total fungi isolated from soil were lower in all treated plots relative to the nontreated control, with the exception of methyl iodide, which had almost twice as many colony forming units of fungi as any other treatment (Table 5). This same trend was observed with *Penicillium* spp. and *Paecilomyces* spp. Methyl bromide had the lowest total number of fungi

Table 4
Pepper plant health and cumulative crop yield in 1998

Treatment	Wilted plants ^{a,b}		Crop yield ^a	
	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'
	%		kg per plot	
1,3-D (drip)	78 a	88 a	1.94 c	0.40 c
1,3-D + C35 (chisel)	12 d	32 b	11.7 a	6.35 b
1,3-D + C35 (drip)	63 ab	78 a	2.19 c	0.48 c
Methyl bromide	22 cd	32 b	7.81 b	10.46 a
Methyl iodide	42 bc	37 b	2.86 c	3.16 c
Nontreated control	81 a	94 a	0.54 c	0.45 c

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^bPepper plants of both *Meloidogyne incognita*-susceptible ('Camelot') and *M. incognita*-resistant ('Charleston Belle') varieties began to wilt and die in approximately three to four weeks after transplanting in 1998 with a differential mortality rate among treatments. Major pathogenic fungi isolated from the roots of dying plants were *Pythium* spp. (primarily *P. aphenidermatum*).

and was the only treatment that was consistently effective in suppressing fungi across all species evaluated (*Pythium* spp., *Fusarium solani*, total *Fusarium* spp., *Trichoderma* spp., *Penicillium* spp., and *Paecilomyces* spp.). Fenamiphos + metham controlled some of the pathogenic fungi, but did not reduce *Fusarium* spp. Both 1,3-D + C35 (chisel) and (drip) did not reduce populations of the beneficial *Trichoderma* spp. and were effective in reducing *Penicillium* spp., *Paecilomyces* spp. and total fungi relative to the nontreated control. However, both treatments had similar populations of *Fusarium solani* and *Pythium* spp. to that of the nontreated control (Table 5).

Fruit yield (kg per plot) of pepper in 1998 was highest with 1,3-D + C35 (chisel) and methyl bromide for 'Camelot' and 'Charleston Belle' cultivars, respectively (Table 4). Differences in fruit yield could not be detected among the nontreated control, methyl iodide, 1,3-D + C35 (drip), and 1,3-D (drip) in either cultivar in 1998. Lower yields from these treatments were probably related to the *Pythium* spp. that caused significant plant wilting and mortality. In 1999, only 1,3-D + C35 (chisel) increased yield above the nontreated control for both 'Charleston Belle' and 'Camelot' cultivars. Fenamiphos + metham and methyl bromide treatments had higher fruit yields than the nontreated controls for 'Charleston Belle' pepper (Fig. 2). However, there were similar fruit yields among 1,3-D + C35 (chisel), 1,3-D + C35 (drip), and methyl bromide for both cultivars, and fenamiphos + metham for 'Charleston Belle', and methyl iodide for 'Camelot' pepper.

Table 5
The effect of soil applied treatments on fungal populations in pepper^a

Treatment	<i>Pythium</i> spp.	<i>Fusarium solani</i>	Total <i>Fusarium</i> spp.	<i>Trichoderma</i> spp. (× 1000)	<i>Penicillium</i> spp. + <i>Paecilomyces</i> spp. (× 1000)	Total fungi (× 1000)
	CFU ^b					
1,3-D + C35 (chisel)	29 cd	420 b	760 bc	75.1 a	0 d	93.5 c
1,3-D + C35 (drip)	109 ab	370 b	880 b	77.5 a	0 d	111.4 b
Fenamiphos + metham	63 bc	1750 b	2450 a	5.3 b	8.2 bc	66.4 c
Methyl bromide	1 d	20 c	120 c	1.5 b	4.4 c	36.3 d
Methyl iodide	257 a	8610 a	9970 a	22.3 a	25.7 ab	213.7 a
Nontreated control	237 ab	970 ab	2400 a	24.2 a	76.7 a	304.9 a

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^bNumber of colony forming units (CFU) per gram of oven-dry soil.

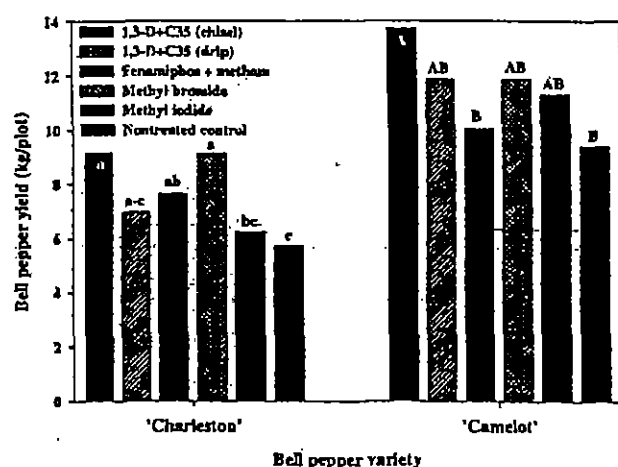


Fig. 2. The effect of soil treatment on pepper yield for both *Meloidogyne incognita*-resistant and *M. incognita*-susceptible pepper varieties in 1999. Treatment means were separated using Fisher's Protected LSD at an alpha level of 0.05; lower case letters were used to differentiate treatments in *M. incognita*-resistant pepper, while capital letters were used to separate treatment means in *M. incognita*-susceptible pepper.

3.2. Squash

Relative to all other treatments, a higher population of *M. incognita* was detected following the first crop treatment of 1,3-D + C35 (chisel) in 'Camelot' pepper that were left nontreated prior to the squash crop in 1998 (Table 6). Differences in *M. incognita* populations could not be detected among all other treatments and the nontreated control for the first crop followed by nontreated control for the second crop in 1998. There were significant differences in number of *M. incognita* recovered from soil among first crop soil treatments in

1999 (Table 7). Treatments of methyl bromide, 1,3-D + C35 (chisel), and fenamiphos + metham applied prior to the first crop resulted in lower *M. incognita* populations than in the nontreated control. There was a significant second crop treatment by pepper cultivar interaction in 1999, which indicated that a treatment of metham applied through the irrigation tubing following the susceptible cultivar of pepper ('Camelot') had lower *M. incognita* soil populations than did the same cultivar that did not have any application for the control of nematodes prior to the second crop. In plots that had resistant pepper cultivar as the first crop, there were no differences in *M. incognita* soil populations between second crop treatments of metham and nontreated plots (Table 7). Previous research indicated that cucumber following nematode-resistant tomato had lower soil populations of *M. incognita* than those following nematode-susceptible tomato (Hanna et al., 1994). Clearly pest resistant cultivars, where possible, should be one component of a methyl bromide alternative system.

Root-gall indices of squash in 1998 indicated no differences among first crop or second crop treatments when squash was planted following the nematode-resistant pepper cultivar ('Charleston Belle') (Table 6). However, there were differences among treatments following the nematode-susceptible cultivar ('Camelot') in 1998. Squash in plots that were treated with methyl bromide (first crop) followed by a nontreated control (second crop) or 1,3-D + C35 (chisel) (first crop) followed by nontreated control (second crop) both had higher root-gall indices than the nontreated control for the first crop followed by nontreated control for the second crop treatment. However, when an application of metham was applied through the drip irrigation tubing prior to the

Table 6

The effect of first and second crop treatments on *Meloidogyne incognita* (southern root knot nematode) population and root-gall indices in the second crop of squash in 1998^a

First crop Treatment	Second crop Treatment	<i>Meloidognye incognita</i>		Root-gall index ^a	
		'Camelot' ^b	'Charleston Belle'	'Camelot'	'Charleston Belle'
		—no. per 150 cm ³ of soil—			
1,3-D (drip)	Metham	5 b	0 b	1.1 c	1.1 c
	Nontreated control	10 b	8 b	1.0 c	1.0 c
1,3-D + C35 (chisel)	Metham	3 b	3 b	1.0 c	1.0 c
	Nontreated control	50 a	8 b	2.2 a	1.3 bc
1,3-D + C35 (drip)	Metham	0 b	0 b	1.1 c	1.0 c
	Nontreated control	10 b	3 b	1.2 bc	1.1 c
Methyl bromide	Metham	5 b	3 b	1.2 c	1.0 c
	Nontreated control	0 b	0 b	1.8 ab	1.0 c
Methyl iodide	Metham	0 b	0 b	1.2 bc	1.0 c
	Nontreated control	0 b	0 b	1.2 bc	1.0 c
Nontreated control	Metham	3 b	0 b	1.0 c	1.0 c
	Nontreated control	8 b	8 b	1.1 c	1.0 c

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter could not be detected.

^bFirst crop treatments included a *M. incognita*-susceptible pepper ('Camelot') and a *M. incognita*-resistant pepper ('Charleston Belle').

^c*Meloidogyne incognita* root-gall index was rated on a scale of 1-5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

Table 7

The effect first crop (pepper) treatments on second crop (squash) nematode population, root-gall index, and crop response in 1999^a

Treatment	<i>Meloidogyne incognita</i> (no./150 cm ³ soil)	Root-gall index ^a	Plant vigor rating ^b	Fruit weight (kg/plot)	Marketable Fruit ^c (%)
1,3-D + C35 (chisel)	9 bc	1.1 b	4.1 b	1.1 b	60 ab
1,3-D + C35 (drip)	26 a-c	1.6 a	5.1 ab	1.0 b	52 b
Fenamiphos + metham	10 bc	1.5 ab	4.4 b	0.9 b	48 b
Methyl bromide	1 c	1.0 b	6.5 a	2.7 a	74 a
Methyl iodide	35 a-c	1.1 b	4.6 ab	1.6 b	74 a
Nontreated control	84 a	1.8 a	4.4 b	1.0 b	55 ab
Interactions					
Metham - 'Camelot'	1 b	1.3	4.9	1.5	58
Metham - 'Charleston Belle'	12 ab	1.2	4.9	1.6	65
Nontreated control - 'Camelot'	73 a	1.7	4.8	1.2	61
Nontreated control - 'Charleston Belle'	24 ab	1.2	4.8	1.2	60

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column above the centerline or in interaction below the center line, could not be detected.

^b*Meloidogyne incognita* root-gall index was rated on a scale of 1-5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

^cPlant vigor was rated on a scale of 1 (least vigorous) to 10 (most vigorous).

^dMarketable fruit were the percentage of the total harvested squash that were not graded as a cull.

second crop, the root-gall indices in all first crop treatments did not exceed a value of 1.2 in 1998 (Table 6).

Root-galls indices in squash in 1999 caused by *M. incognita* indicated that there was no effect of the second crop treatments. However, there was an effect of the first crop soil treatments on the second crop root-gall indices (Table 7). Methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) had lower root-gall indices than the

nontreated control. Fenamiphos + metham and 1,3-D + C35 (drip) were not different from the nontreated control. While there was no significant interaction among pepper cultivars and second crop applications in root gall ratings, the trend in root-gall indices reflected the numbers of *M. incognita* in the soil (Table 7).

Squash plant vigor was influenced by the first crop treatments and was greatest in methyl bromide treated

plots (Table 7). All other treatments were not different from the nontreated control. Differences in plant vigor could not be detected among second crop treatments nor related to the cultivar of the previous pepper crop. Higher plant vigor ratings from the methyl bromide treatment resulted in higher squash yields relative to all other treatments in 1999 (Table 7). The nontreated control was similar in yield to all other nonmethyl bromide treatments. Differences in crop yield in 1998 among treatments could not be detected (data not shown). Approximately 74% of the harvested fruit were marketable from the methyl bromide and methyl iodide plots in 1999, but this was not different from the nontreated control (Table 7). These values were higher than those from plots treated with 1,3-D + C35 (drip) and fenamiphos + metham. Second crop treatments did not have any detectable effect on plant vigor rating, fruit weight, or the percent of marketable fruit (Table 7).

Nutsedges were identified as the most troublesome weeds of vegetable crops in Georgia (Webster and MacDonald, unpublished). While purple nutsedge was a problem during the first crop, the presence of this weed species was erratic in the second crop. Differences in purple nutsedge densities among treatments could not be detected in the second crop in 1998 or 1999, nor could any trends within the data be observed (data not shown). Treatment of the plots between the first and second crop with glyphosate probably had a significant influence on the reduction of purple nutsedge shoots in the second crop. With the exception of the methyl bromide treatments, all plots had purple nutsedge shoot densities greater than 5/m² emerged through the polyethylene and measured 25-61 cm in height at the time of glyphosate treatment. This application of glyphosate reduced the purple nutsedge shoot population in the second crop 82-99%, regardless of the second crop treatment. The nonselective herbicide paraquat is often used to eliminate weedy vegetation between vegetable crops, primarily because of its low price, quick action, and broad spectrum of weed control. However, this will often only provide contact burn of exposed purple nutsedge foliage and will not control any underground tubers. Glyphosate was reported to control nutsedge tubers that were attached to treated foliage (Doll and Piedrahita, 1982). These researchers found that new shoots of purple nutsedge that emerged following glyphosate applications originated from dormant tubers. Based on the reduced nutsedge populations observed in the current study, an application of glyphosate between crops is recommended to assist in weed control in a plasticulture system. However, results of this study indicate that an effective replacement for methyl bromide for weed control within the crop has not yet been found.

Many pests were controlled effectively with methyl bromide (nematodes, soil-borne plant pathogenic fungi, soil-borne insects, and weeds), however, the potential

methyl bromide-replacements investigated in this study do not have the broad-spectrum pest control of methyl bromide. Following the elimination of methyl bromide, pest management in vegetable crops will need to further rely on the principles of integrated pest management (IPM). Correct identification of pests and implementation of appropriate control measures have become increasingly important in the effective management of pests in systems that previously relied on methyl bromide. Instead of a limited number of pest control tactics, new pest management systems will need to rely on multiple components aimed at controlling weeds, nematodes, and soilborne plant pathogenic fungi and insects. These systems in the future may also include a broader arsenal of herbicides for several crops with minor hectareage due to the efforts of the US Interregional Research Project 4 (IR-4) (<http://pestdata.ncsu.edu/ir-4/>), which is a collaborative effort between the State Agricultural Experiment Stations and the USDA-Agricultural Research Service. In addition, integration of cultural practices such as crop rotation (McSorley, 1996), pest resistant cultivars (Thies and Fery, 1997), stale seed bed techniques (Johnson and Mullinix, 1998), precision fertilization and watering, the use of organic amendments (Blok et al., 2000; Gardiner et al., 1999; Kirkengaard and Sarwar, 1999) and the choice of polyethylene mulch (Chase et al., 1998; Patterson, 1998) may also improve pest control and should be investigated across multiple disciplines in future studies.

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For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: soil solarization

[Insert Alternative]

Application of soil solarization
Study: to full production of cucurbits of
[Insert Study Title] pepper

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted _____

1b. Township caps _____

1c. Alternative not acceptable in consuming country _____

1d. Other (Please describe) X

This alternative can be used in pepper, tomato, strawberry and
cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website?

Yes _____

No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Chellemi, Hochmuth, Winsberg, Guetler, Shuler,

Datnoff, Kaplan, McSorley, Dunn & Olson

3. Publication and Date of Publication

Proc Florida State Hort. Soc., 1997

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
solarization

6. Was crop yield measured in the study?

Yes X

No _____

pepper
cucumbers

7. Describe the effectiveness of the alternative in controlling pests in the study.

Weed density (yellow and purple nutsedge was greater in the solarized treatments
compared to the methyl bromide treatment. Yield was higher in the methyl
bromide treatments in cucumbers and peppers.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Our growers would not use this alternative because it is even less effective
in controlling yellow and purple nutsedge in the cooler climate of North Carolina.
Similar results would be expected in tomato, and strawberry.

Research Summary Table

Alternative: Soil solarizationStudy: Chellemi et al., 1997

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. al per area)	Pest 1: Yellow and Purple Nutsedge Density						Pest 2						Yield (tons/acre)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	solarization		101	0.22											15.8 11
2	98/2 methyl bromide + chloropicrin	300 lbs./acre	58	0.04											16.8 14

Comments: Plants per foot of row; yield estimated from graph in study report; yield data = Peppers | Cucumbers.

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Col. A: Name of Product and Non-chemical Control

Col. B: Target Posts

Col. C: Active Ingredients

Col. D: Formulation

Col. E, F, G: Application Rate

Col. H, I, J: Prices and Costs

Col. K: Area Treated

Col. L: # of Applications per Year

Col. M: Cost per Area in 2001 Dollars

Non-chemical Control

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments: Hand weeding nutsedge is impossible and would likely be over \$2,000 per acre.

Soil solarization

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle.

Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.

Enter the unit of measurement for your crop/commodity.

Enter the number of units of crop/commodity produced per area for that price factor identified.

Enter the average 2001 prices received by the users for that crop/commodity and price factor.

In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

A

C

1

E

F

Total Revenue

OMB Control # 2060-0482

03-0041

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Soil solarization

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No other changes except that hand removal of nutsedge is going to be impossible due to time constraints and the cost of labor.

APPLICATION OF SOIL SOLARIZATION TO FALL PRODUCTION OF CUCURBITS AND PEPPER¹

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Abstract. Soil solarization, applied alone or in combination with 1,3-dichloropropene or municipal solid waste compost, was evaluated as an alternative to preplant fumigation with methyl bromide. In Palm Beach County, marketable yield of pepper was 15.3 and 16.4 tons per acre from solarized and methyl bromide treated areas, respectively, while suppression of nut-sedge and density of root-knot nematodes were similar under both treatments. Following a subsequent second crop of cucumber, reductions in marketable yield and increases in the severity of root gallings and density of root-knot nematodes were observed in the solarized area. In Washington County, severe root gallings and high densities of root-knot nematodes were observed in untreated or solarized areas but not in an area treated with soil solarization plus 1,3-dichloropropene. In Suwannee County, suppression of yellow and purple nutsedge was similar in plots receiving soil solarization or methyl bromide while reductions in root gallings and density of root-knot nematodes were greatest in plots treated with methyl bromide. Marketable yield of cucumber was greatest in methyl bromide-treated areas.

Introduction

Methyl bromide is considered a key component in many Florida fresh market vegetable production systems (Cantliffe et al., 1995). Recently, methyl bromide has been implicated as a major ozone depleting substance, and production and sale within the United States will be eliminated after January, 2001 (Federal Registrar, 1993). In the absence of methyl bromide, production of eggplant, pepper, and tomato is projected to decline by 100%, 63%, and 69%, respectively (Spren et al., 1995). Furthermore, yields of subsequent (double) crops of cucurbits also are expected to experience dramatic reductions. In Florida, soil solarization has been examined for its effect on soilborne pests of tomato in the Homestead, Bradenton, and Quincy production regions (Chellemi et al., 1993; 1997; McSorley and Parrado, 1986; Overman, 1985). While yields similar to those obtained after fumigation with methyl bromide were obtained, control of specific pests varied from location to location. Information regarding the potential of soil solarization for additional Florida-produced commodities is not available. The objective of this study was to examine the impact of soil solarization, performed alone or in combination with other management tactics, on soilborne pests and production of pepper, cucumber, and pumpkin.

Materials and Methods

Soil solarization was evaluated on cucumber, pepper, and pumpkin in Suwannee, Palm Beach, and Washington Counties, respectively. Crops were planted in the fall following a summer solarization period. The pepper crop was followed by a double-crop of cucumber in the spring.

Pepper. Soil solarization was performed in a plot consisting of 10 adjacent beds, 2400 ft in length (3.3 acres). The soil type was a Myakka sand. Beds were oriented north/south on 5.5 ft centers. On 16 July, compost and mineral fertilizer was broadcast over the plot. The rates used were 28 tons per acre of biosolids compost (a mixture of biosolids composted with yard

Additional index words. *Cucumis sativus*, *Cucurbita pepo*, *Cyperus* s., *Capsicum annuum*, *Meloidogyne* spp., municipal solid waste compost, *Phytophthora capsici*.

The authors would like to thank Pat Byers and the Palm Beach County Waste Authority for providing biosolids compost and application assistance. Mention of a trademark, warranty, proprietary product, or vendor does not constitute a guarantee by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that also be suitable.

Table 1. Soil amendments utilized for the production of pepper and cucumber in Palm Beach county.

Treatment	Soil amendment	lbs per acre (N-P-K)
Solarization	BC (28 T per acre)	280-181-59
	MSW ^a (1.1 T per acre)	110-28-0
	mineral fertilizer	73-39-38
	Total	463-248-97
Methyl bromide mineral fertilizer		377-43-220

Other treatments were side dressed with 30-0-7 lbs per acre of N-P-K prior to planting the double-crop of cucumber.

^a Solids compost (a mixture of composted municipal solid waste and composted yard waste), Palm Beach County Solid Waste Authority; composted municipal solid waste, Wheelabrator sludge, Queens, New York.

aste, ca. 50% moisture, Palm Beach County Solid Waste Authority), 1.1 tons per acre of dried municipal solid waste compost (Wheelabrator Sludge, Queens, New York) and 73-39-38 lbs of N-P-K per acre (Table 1). Soil solarization was initiated 7 July on 8-inch tall, 36-inch wide beds using 1.2 mil, clear, low density polyethylene (LDPE) plastic containing UV light inhibitors (AEP Industries, Hackensack, NJ).

In a nearby plot of the same dimensions, mineral fertilizer was applied (Table 1) and the soil was fumigated with methyl bromide plus chloropicrin (98:2) at 300 lbs per treated acre on 28 August. After fumigation, beds were immediately covered with a co-extruded, white-over-black, 0.7 mil thick, high density polyethylene plastic (Sonoco Products Co., Orlando, FL).

Solarization was terminated after 51 days (6 Sept.) by painting the plastic white using a latex based paint (Kool Grow, Gainesville, FL). Pepper (cv Boynton Bell) was transplanted on 16 Sept., two rows per bed, into the solarized and methyl bromide-treated plots. Subsurface (seepage) irrigation was used. Yield from six subplots (16 ft of row) located randomly within each main plot was assessed on 18 and 26 Nov. Marketable yield was also obtained from grower packout data on 21 Nov., 2 and 20 Dec.

Weeds protruding from the plastic or the plant hole in six 50 ft long subplots were counted on 3, 31 Oct. and 25 Nov. The incidence of *Phytophthora* root and crown rot was assessed on 27 Nov. by recording the number of diseased plants in the center four rows of each plot. The severity of root-galling by root-knot nematodes was assessed on 27 Dec. by physically removing four plants from each subplot and determining the severity of galling using a scale of 0 to 5 (Taylor and Sasser, 1978). Soil samples for nematode analysis were collected on 27 Dec. by removing and combining soil cores 1 inch in diameter and 8 inches deep from the root zone of six plants per subplot. Nematodes were extracted from 100 cm³ soil subsamples with a modified sieving and centrifugation procedure (Jenkins, 1964), and then identified and counted. Following the last pepper harvest, the plants were mowed and rows were side dressed with 250 lbs per acre of 12-0-4 N-P-K. New holes were punched into the plastic and cucumber (cv. Speedway) was planted. Cucumbers were harvested on four dates and yield was obtained using packout data. Root systems were assessed for galling and soil samples for nematode analysis were collected on 24 Mar.

Cucumber. Three treatments were arranged in a randomized complete block design with four replications per treatment. Treatments consisted of soil solarization, fumigation

with methyl bromide plus chloropicrin (98:2), and an untreated control. Each plot was a single row 75 ft in length. Rows were spaced 5 ft apart on centers. Solarization was initiated on 6 June on raised beds using clear, 1.2 mil, LDPE with UV inhibitors (Polyon-Barkai, Israel). Prior to solarization, 65-20-65 lbs of N-P-K was applied to the beds. The solarization period was terminated after 65 days (10 Aug.) by painting the clear plastic white.

Methyl bromide plus chloropicrin (98:2) was applied on 1 Aug. and plots were immediately covered with a co-extruded white over black, 1.2 mil LDPE (AEP Industries). Plastic mulch was also applied to untreated control beds on 1 Aug.

Cucumber (cv. Dasher II) seeds were planted on 30 Aug. at a 12-inch spacing with two rows per bed. Weekly injections of 1 lb N + 1 lb K per acre were made beginning 1 Sept., using drip irrigation. Stand and weed count were assessed on 20 Oct. Plots were harvested on 10, 13, 16, 18, and 23 Oct. The severity of root-galling was assessed on 26 Oct. Soil samples were collected for nematode analysis on 30 Oct.

Pumpkin. Three treatments, consisting of soil solarization, solarization plus 1,3-dichloropropene (1,3-D), 8.0 gal per treated acre) and an untreated control were applied to non-replicated 10.5, 3.1, and 0.1 acre plots, respectively. The solarization and fumigation treatments were applied on 2 June to raised beds (6 by 36 in) using 1.2 mil LDPE (AEP Industries). The untreated control treatment consisted of 1.2 mil co-extruded, white over black LDPE film (Edison Plastics, Newport News, VA) and was applied on 6 June. Solarization was terminated after 34 days by painting the plastic white.

Plots were harvested on 30 Sept. Fruit within a 0.1 acre section of row were harvested and weighed for each treatment. Root gall ratings were taken on five plants in each treatment, and soil samples for nematode densities were collected from the base of five plants in each treatment.

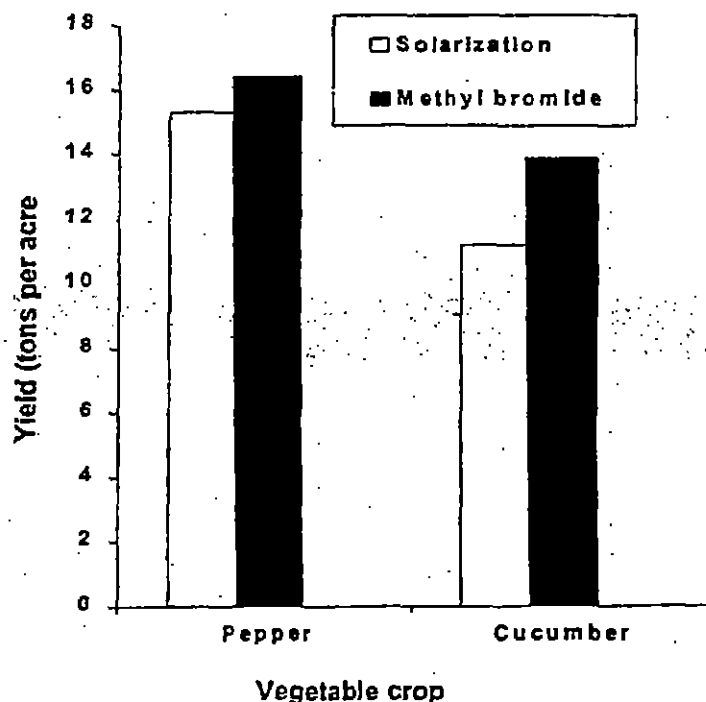


Figure 1. Marketable yield of pepper and a double-crop of cucumber from solarized and methyl bromide-treated plots in Palm Beach County.

Table 2. Effect of solarization and compost on soil-borne pests of pepper and cucumber in Palm Beach County.

Treatment	Phytophthora blight ^a	Meloidogyne incognita ^b	Root gall ratings ^c	Weed density ^d
Pepper				
Methyl bromide	2.5%	1.6	0	0.22
Solarization	2.3%	0	0	0.04
Cucumber				
Methyl bromide	—	1,682	1.04	—
Solarization	—	0	0.04	—

^aDisease incidence.
^bDensity of nematodes per 100 cm³ of soil.
^cEstimates of the number of galls per root system using a scale of 0 to 5 in which 0 = no galls and 5 = > 100 galls (Taylor and Sasser, 1978).
^dNumber of weeds emerging through the plastic per ft of row.
^eMunicipal solid waste compost.

Results and Discussion

Marketable yields of pepper were 1.1 ton per acre greater with methyl bromide than with solarization (Fig. 1). Pest levels were low in both treatments (Table 2). In the double-crop cucumber, marketable yields were 2.7 ton per acre higher with methyl bromide (Fig. 1). There was a large increase in root galling and density of root-knot nematodes with solarization. *Meloidogyne incognita* was subsequently identified from these soil samples.

In Suwannee County, the highest yields of fancy, number 1 and number 2 cucumbers were obtained from the methyl bromide-treated plots (Fig. 2). Yields were 3.1 tons per acre higher than yields in solarized plots and 8.1 tons per acre higher than the untreated control plots. Density of root-knot nematodes reached 73 per 100 cm³ of soil in the nontreated soil as compared with 21 in the solarized plots and 2.5 in the methyl bromide-treated plots (Fig. 3). Both solarization and methyl bromide appeared to control stubby-root (*Trichodorus* sp.) and ring (*Cricanemoides* spp.) nematodes. Densities of lesion (*Belonolaimus* spp.) and lesion (*Pratylenchus* spp.) nematodes were low with all three treatments. Root gall indices were 0.7, 1.6, and 3.1 in the methyl bromide, solarized, and control plots, respectively. Late-season stand counts for cu-

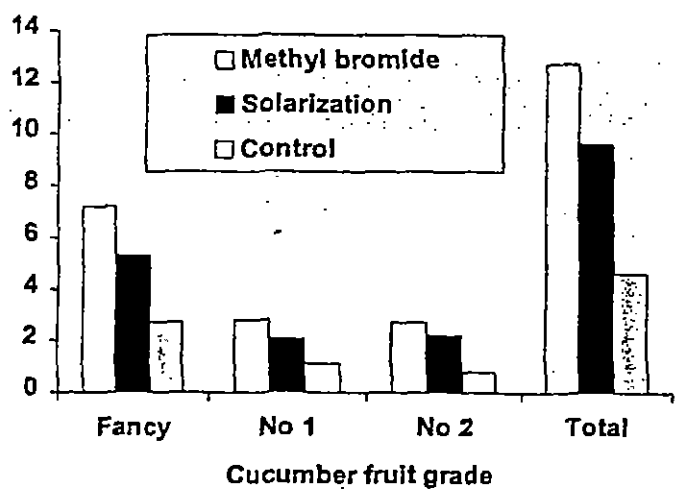


Figure 2. Marketable yield of cucumber from solarized, methyl bromide and untreated plots in Suwannee County.

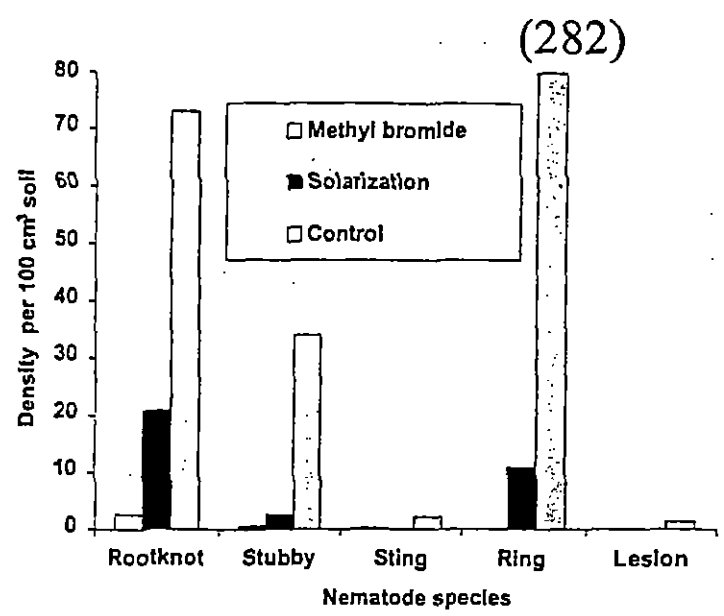


Figure 3. Density of plant parasitic nematodes following production of cucumber in Suwannee County.

cumber were 100%, 100%, and 40% for the methyl bromide, solarized, and untreated plots, respectively.

Highest yields of pumpkin were obtained with the nontreated control, followed by solarization plus 1,3-D, and solarization (Table 3). The differences in yield may be due to uneven pollination in the field as a greater number of fruit was observed in the nontreated area of the field. High densities of *Meloidogyne* spp. and severe root galling were observed in the control and solarization treatments. Combining solarization plus 1,3-DCP eliminated root galling and the high density of *Meloidogyne* spp. Weed densities were similar in both solarized treatments and were well below the untreated control.

Soil solarization is a hydrothermal process which utilizes clear plastic stretched over moistened soil to trap solar energy and heat the soil (Stapleton and DeVay, 1995). When extended over a 4 to 8 week period of time, this procedure has been shown to control many of the soilborne pests which threaten the Florida fresh market vegetable production industry (Chellemi et al., 1997; Heald and Robinson, 1987; Ristaino et al., 1991, 1996). In this study, solarization did not control root-knot nematodes on cucurbit crops, especially in the cucumber crop that followed pepper. Combining solarization with 1,3-D provided control of nematodes, as was observed in

Table 3. Effect of solarization and 1,3-dichloropropene on yield of pumpkin and the incidence of soilborne pests.

Soil	treatment	Fruit T per acre	<i>Meloidogyne</i> spp. ^a	Root gall ratings ^c	Weed density ^d
Clear	—	4.4	1,468	4	0.10
Clear	1,3-DCP ^e	5.3	0	0	0.00
White ^f	—	6.0	933	3	2.53

^aDensity of nematodes per 100 cm³ of soil.
^bEstimates of the number of galls per root system using a scale of 0 to 5 in which 0 = no galls and 5 = > 100 galls (Taylor and Sasser, 1978).
^cNumber of weeds emerging through the plastic per ft of row.
^d1,3-dichloropropene applied at 8 gal per broadcast acre.
^eUntreated control.

other studies (Cartia et al., 1989; Chellemi et al., 1997). Soil samples measured for nematode density did not contain root-knot species for any of three locations prior to planting. Thus, it is advisable to include treatments for the management of root-knot nematodes when utilizing solarization for cucurbit production.

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02-0041
3-A(1)a study

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: soil solarization
(Insert Alternative)

Study: Effect of methyl bromide, 1,3-D chloropicrin with pebulate.....
(Insert Study Title)

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

This alternative can be used in pepper, tomato, strawberry and
cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes No
 1a. If not on the EPA website, please attach a copy.
2. Author(s) or researcher(s) Gilreath, Noling, Locascio and Chellemi

3. Publication and Date of Publication Proc. Fla. State Hort. Soc.

4. Location of research study Florida, 1999

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
 solarization

6. Was crop yield measured in the study? Yes X No Tomato
7. Describe the effectiveness of the alternative in controlling pests in the study.
 The alternative did not control purple nutsedge effectively in tomato.
 Similar results would occur in cucurbit crops, pepper and strawberry.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?
 This work was conducted in Florida which has a warmer climate than North
 Carolina. This alternative would be even less effective in our state due
 to soil temperatures not reaching levels high enough to kill nutsedge rhizomes.
 Expect similar results in cucurbit crops, pepper and strawberry.

Research Summary Table

Alternative: Soil solarizationStudy: Gilreath, Nolting, Locascio and Chellemi, 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. a/ per area)	Pest 1: Purple Nutsedge (no. per 210 ft. row)						Pest 2: Crabgrass (no. per 210 ft. row)						Marketable Tomato Yield (boxes/acre)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		42 DAT	540					42 DAT	42					1,058
2	67/33 methyl bromide	350 lbs.	42 DAT	6					42 DAT	1					3,270
4	solarization	8 weeks	42 DAT	228					42 DAT	34					1,997

Comments: DAT = days after tomato transplanting; yield is of tomato, a related crop; yield is reported in 25 lb. boxes per acre.

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Col. A: Name of Product and Non-chemical Control

Col. B: Target Pests

Col. C: Active Ingredients

Col. D: Formulation

Col. E, F, G: Application Rate

Col. H, I, J: Prices and Costs

Col. K: Area Treated

Col. L: # of Applications per Year

Col. M: Cost per Area in 2001 Dollars

Non-chemical Control

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments: Hand weeding nutsedge is impossible and would likely be over \$2,000 per acre.

Soil solarization

If a consortium is submitting this application, the data for this table should reflect a representative user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 pounds)	1,997.00	\$ 6.50	\$ 12,980.50
				Total Revenue	\$ 12,980.50

Comments:

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Soil solarization

If a consortium is submitting this application, the data for this table should reflect a <i>representative user</i> .					
Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.					
Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.				
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.				
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.				
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.				
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.					
A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		
Comments: No other changes except that hand removal of nutsedge is going to be impossible due to time constraints and the cost of labor.					

Vegetable Section

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EFFECT OF METHYL BROMIDE, 1,3-DICHLOROPROPENE + CHLOROPICRIN WITH PEBULATE AND SOIL SOLARIZATION ON SOILBORNE PEST CONTROL IN TOMATO FOLLOWED BY DOUBLE-CROPPED CUCUMBER

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Abstract. Soil fumigation with 1,3-dichloropropene (1, 3-D) + chloropicrin (Telone C-17) with pebulate (Tillam) and soil solarization + *Gliocladium virens* (SoilGard™) were compared to no fumigation with methyl bromide for control of soilborne pests and crop response for fall tomatoes (*Lycopersicon esculentum* Mill.) and double-cropped spring cucumbers (*Cucumis sativus* L.) In 1998-99. Soil treatments were applied prior to the fall tomato crop and soil solarization was conducted for 6 weeks pre-plant. *G. virens* was applied to the tomato plants a drench in the setting water at transplanting. The combination of pebulate and 1,3-D + chloropicrin provided nutsedge (*Spergularia rotundus* L.), Fusarium wilt (race 3, incited by *Fusarium oxysporum* f.sp. *lycopersici*) and root knot nematode (*Medogynae* spp.) control and tomato yields similar to that obtained with methyl bromide, but soil solarization did not. Soil solarization, 1,3-D + chloropicrin + pebulate and methyl bromide provided statistically similar control of nutsedge, though a wide spread numerical difference occurred between methyl bromide and the other two treatments, but there was more crabgrass in solarized plots than in those which received either of the two fumigants. Root gall formation on tomato due to rootknot nematodes was worse with solarization than with either other treatment, including the nontreated control and the incidence of Fusarium wilt was intermediate between that of the fumigants and the nontreated. Tomato fruit production

with 1,3-D + chloropicrin + pebulate was equal to that with methyl bromide, but solarization resulted in fewer fruit in each size grade and total marketable yield. Tomato production with soil solarization + *G. virens* drench was only slightly higher than that obtained without fumigation. When cucumbers were grown as a double crop in the spring following fall tomatoes, yields were similar with 1,3-D + chloropicrin + pebulate and methyl bromide. Solarization + *G. virens* drench reduced cucumber yield relative to methyl bromide but was similar to that of 1,3-D + chloropicrin + pebulate. Rootknot nematode galling of second crop cucumber, was similar with soil solarization, 1,3-D + chloropicrin + pebulate, and no fumigant. Gall formation was not significantly different between methyl bromide and 1,3-D + chloropicrin + pebulate, whereas methyl bromide greatly reduced gall severity compared to solarization. Methyl bromide improved millet growth in the spring following fall application compared to solarization or no treatment, but was not different with 1,3-D + chloropicrin + pebulate. Fewer crabgrass plants were present in millet grown in soil treated with either methyl bromide or 1,3-D + chloropicrin + pebulate than with no fumigant or with soil solarization.

Methyl bromide combined with chloropicrin for soil fumigation has been the mainstay of the mulched vegetable production system in Florida for many years (Overman and Jones, 1984). The impending loss of methyl bromide as a soil fumigant has resulted in considerable research into alternatives, both chemical and nonchemical (Gilreath et al., 1994; Locascio et al., 1997; Jones et al., 1995; Chase et al., 1997a, b; Chellemi et al., 1997). Previous research has demonstrated the efficacy of 1,3-D + chloropicrin when combined with pebulate as an alternative package for soil fumigation in tomato production (Gilreath et al., 1994; Locascio et al., 1997; Gilreath et al., 1997). In most cases, this combination has resulted in tomato yields similar to those achieved with methyl bromide. Soil solarization has provided good nutsedge control when used during the summer months and has been proposed as an alternative to methyl bromide (Chase et al., 1997a, b; Chellemi et al., 1997). Most of the research conducted to date has focused on the effects of alternatives on a first crop, mostly tomato, and little work has addressed the residual effects on a double-crop, such as cucumber. No one has investigated potential effects of fall fumigation on spring cover cropping practices.

The purpose of this research was to compare standard methyl bromide soil fumigation to fumigation with the best chemical alternative, a mixture of 1,3-dichloropropene (1,3-D) and chloropicrin used in combination with pebulate, and the best nonchemical alternative, soil solarization combined with a plant drench of a commercial preparation of *Gliocladium virens* (SoilGard, Thermo Trilogy Corp.), for soilborne pest control and crop response in both fall tomatoes and spring double-cropped cucumbers and to determine any ef-

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these fall treatments may have on a spring planted millet crop.

Material and Methods

The experiment was conducted at the Gulf Coast Research and Education Center in Bradenton, FL on an Eau Gallie sand soil during the fall of 1998 and the spring of 1999. Subsurface irrigation was applied during the summerization period and the first half of the tomato crop then remainder of the tomato crop and all of the spring cucumber crop was irrigated with drip irrigation. Treatments assigned to 3 bed plots 210 ft in length arranged in a randomized complete block design and replicated 6 times. Beds spaced 5 ft apart on centers and were 30 inches wide and 12 inches high. Plots were subdivided into three 70 ft long subplots for spring treatments. Treatments consisted of a non-treated control, methyl bromide and chloropicrin (67/33%, respectively) at 350 lbs./acre, 35 gal/acre of a mixture of 1,3-D and chloropicrin (83/17%, respectively) with pebulate hericide (4 lb/acre) applied prior to fumigant application), 8 weeks of soil solarization combined with *G. vires* as a soil drench (1 lb/100 gal) the day after transplanting. Soil solarization began on 28 July 1998 and ended on 15 Sept. 1998. The 1.25 mil thick, clear polyethylene mulch film was coated white with latex paint, using a minimum of 3 coats to insure transmission of long wave radiation of the clear polyethylene film. Starter fertilizer (30, 22, 42 lb of N, P and K, respectively) was broadcast on the fields in the solarization plot areas just prior to preparation of the beds and was incorporated with a spring tine harrow. Starter fertilizer was applied in the same fashion to the areas for the other treatments prior to application of pebulate. Pebulate was applied to soil surface pre-bed in 29 gal/acre of spray preparation by a tractor mounted sprayer and incorporated 6 to 8 inches deep in one pass with a spring tine harrow (field cultivator) on 3 Aug. 1998. Beds were formed on 5 Aug. 1998 and methyl bromide and 1,3-D/chloropicrin were applied that day with a standard pressurized fumigation rig on a superbedder equipped with 3 chisels per bed spaced 12 inches apart. Fumigant flow was controlled by a flow meter which was calibrated to deliver the specified quantity of fumigant about 2 inches above the bottom of the finished bed. Fertilizer (150 and 173 lb/acre of N and K, respectively) was applied in two bands on either side of the bed surface, 10 inches from the bed center. Drip tubing was applied to the bed center and the beds were covered with white on black high density polyethylene immediately following the fumigant application. Seven days preplant, all solarization and nontreated control plots were sprayed with paraquat (0.5 lb/acre) to desiccate existing weeds and cover (primarily purple nutsedge) so it would not interfere with early plant growth. Methyl bromide and 1,3-D treatments were not sprayed because no nutsedge had emerged. Two-week-old 'Solimar' tomato plants were transplanted 2 ft apart into the beds on 17 and 18 Sept 1998. Plants received insecticide in the transplant water to control silverleaf whitefly early in the season. Plants were sprayed with fungicide weekly to protect against foliar diseases and insecticides were applied on an as needed basis. Fertigation began about 4 weeks before the first harvest and 1.5 lb/acre of N was applied daily for the remainder of the season. Purple nutsedge (*Cyperus rotundus* L.) plants were counted on 9 Sept., 29 Oct. and 20 Nov. 1998. Pigweed and crab-

grass, the two other weeds present with sufficient uniformity, were counted 29 Oct. 1998. Survival of tomato plants was determined on 13 Oct. 1998 by counting the number of plants per subplot and tomato plant vigor was evaluated twice (13 Oct. and 12 Nov. 1998) using a percentage visual assessment scale where 100% represented optimum plant vigor and 0 indicated the plants were dead. Soil samples were collected from each plot on 6 Nov. 1998 and were sent to a commercial lab for soil mineral analysis to determine if there were any differences in nutritional status of the soil at midseason. Additional soil samples were collected twice during the tomato crop and composition of the soil microflora and fauna was determined by counting colonies on dilution plates of diagnostic media. Soil samples for nematode analysis were collected from the rhizosphere of tomato plants at the time of the last harvest and the nematodes were separated from 100 cc of soil by using a standard sieving and centrifugation procedure (Jenkins, 1964). The numbers of rootknot (*Meloidogyne* spp.) and sting (*Belonolaimus* spp.) nematodes were counted. The crowns and associated roots of 5 tomato plants were dug from each plot and the severity of rootknot nematode gall formation was evaluated using a 0 to 8 rating scale where 0 represented no galls present and 8 indicated plants which were severely galled. The number of tomato plants infested with Fusarium wilt (race 3, incited by *Fusarium oxysporum* f. sp. *lycopersici*) from each 32 plant subplot was counted on 25 Nov. and 7 Dec. 1998 and the numbers were expressed as a percentage of the actual number of plants originally in each plot. Tomatoes were harvested 3 times (1, 14 and 29 Dec. 1998). Fruit were manually separated into marketable and cull categories then marketable fruit were sorted by size into the standard extra large (5 x 6), large (6 x 6) and medium (6 x 7) size grades and weighed. At the end of the season, all tomato plants and weeds were sprayed with a foliar application of paraquat (1 lb/acre) using a boom sprayer with drops fitted with 4 nozzles per bed to kill the tomatoes and the weeds. The tying twine, stakes and polyethylene mulch were left in the field and a second application of paraquat was made to all plots two weeks before planting cucumbers in the spring.

Double-cropped cucumber. 'Competitor' cucumbers were direct seeded into the beds in hills spaced 2 ft apart (3 seed per hole, thinned to 1 plant per hole) in the first 70 ft-long subplot of each main plot on 18 Feb. 1999. The crop was grown using drip irrigation delivering an average of 1.5 lb N/acre per day. Fungicide was applied weekly while insecticide was applied as needed. Early emergence of cucumbers was determined by counting the number of plants on 11 March 1999 and cucumber plant vigor was evaluated on 23 Apr. The number of weeds of the principal weed species were counted on 13 Apr. 1999. The degree of galling due to rootknot nematodes was determined on 25 May 1999 after the last harvest by inspecting the roots and crowns of five cucumber plants in each plot and visually assessing the extent of damage using the aforementioned 0 to 8 rating scale. Cucumbers were harvested eight times from 20 Apr. through 14 May 1999 and the number and weight of marketable fruit were determined.

Millet cover crop. 'Brown top' millet was planted in one subplot per main plot on 22 Mar. 1999. The millet was allowed to grow using only residual fertilizer from the fall tomato crop. Some irrigation in the form of subsurface irrigation was supplied to the millet during the course of the spring. No pesticides were applied to the cover crop. Once millet seed had begun to set, a 5.5 ft² sample area was selected randomly with-

each millet plot and the number of weeds by species were counted within this area. Millet plant height was measured. canopy coverage was estimated visually, and the fresh weight of millet plants was determined on 25 May 1999.

Results and Discussion

Fall tomato. Early season establishment and survival of tomato plants, as measured by plant stand, was better with methyl bromide and 1,3-D treatments than in the nontreated plots (Table 1). Early survival of tomato plants with soil solarization was similar to that in the nontreated plots. Tomato plants were more vigorous in soil treated with methyl bromide and 1,3-D + chloropicrin + pebulate than in soil which received no chemical treatment. Fumigation with methyl bromide was superior to soil solarization at both evaluation dates. The combination of 1,3-D + chloropicrin + pebulate improved tomato plant vigor over what was observed with soil solarization at the second evaluation in November. Plant vigor was similar with soil solarization and no treatment.

By early Sept. before transplanting, nutsedge had begun to emerge and penetrate the mulch in all of the plots (Table 1). There were fewer nutsedge plants in all treated plots than in the nontreated plots at this time. Even though the number of emerged nutsedge plants in the solarization plots was statistically less than that observed in the nontreated control plots, both the nontreated and the solarization plots were sprayed with paraquat to eliminate a large number of existing nutsedge so it would not interfere with transplanting operations and to give tomato plants a chance to become established. As a result, subsequent observations on nutsedge populations in the nontreated and soil solarization plots were skewed to the low side by the fact that all of the nutsedge in those plots was sprayed whereas the methyl bromide and 1,3-

D plots did not receive paraquat. Thus, there was a decrease in the number of emerged nutsedge plants in the nontreated plots from the time of the first count in early Sept. to the second one in late Oct. Both fumigants and soil solarization reduced nutsedge compared to the nontreated throughout the season and there was no statistically significant differences in the number of nutsedge plants between either fumigant or between the fumigants and soil solarization. There was considerable variation in nutsedge populations among the fields used in this study and this, no doubt, impacted the analysis of variance and results. Numerically, there was more nutsedge in 1,3-D plots and soil solarization than in methyl bromide treated areas. The poor control obtained with 1,3-D + chloropicrin + pebulate may be due to the fact that the soil was not overly moist at the time of application of pebulate and it dried even further as a result of aeration due to herbicide incorporation with an s-tine harrow. Bed preparation was delayed in order to bring the moisture back up so the soil would form a good bed and fumigation would improve. Pigweed (*Amaranthus hybridus* L.) control was good with all treatments relative to the nontreated, but only the fumigant treatments reduced crabgrass [*Digitaria ciliaris* (Retz.) Koel.]. Crabgrass was observed growing in many plant holes in the mulch in the solarized plots and in the nontreated areas. Even with a heavy coating of latex paint on the clear plastic, considerable crabgrass and nutsedge were growing under the mulch and in places the film was not touching the soil due to this growth.

After the final tomato harvest (Table 3), the most severe root galling was observed with soil solarization. The extent of galling was not severe in the test but was much higher with solarization than occurred with any other treatment, including the nontreated control. Methyl bromide resulted in no gall formation while plants grown in soil treated with 1,3-D had a slight amount of galling which was not statistically different from either that observed on the nontreated plants or the methyl bromide plants. There was no significant difference among treatments in the number of rootknot or sting nematodes recovered from soil samples at this time, reflecting some variability among replications used in this experiment.

Fusarium wilt was present in the tomato plants. At the end of the season, about 38% of the plants in the nontreated plots displayed symptoms of infestation with Fusarium wilt (Table 3). The relative ranking of treatments did not change from the first evaluation on 25 Nov. to the last on 7 Dec., but the number of plants infested increased for each treatment. Soil fumigation with either methyl bromide or 1,3-D resulted in few tomato plants with symptoms of Fusarium wilt and both fumigants were superior to either soil solarization + *G. virens* or the nontreated control in reduction of the incidence of Fusarium wilt of tomato. Soil solarization + *G. virens* reduced the incidence compared with no treatment but the level of infestation

Table 1. Effect of fall applied methyl bromide alternatives on early season tomato plant stand and plant vigor, Fall 1998.

Treatment	Rate/acre	Plant stand (No./subplot)	Plant vigor (%)	
			19 Oct	12 Nov
Nontreated	0	26 b ^a	60 c	67 b
Methyl bromide	350 lb	32 a	94 a	99 a
1,3-D + chloropicrin	35 gal	32 a	90 ab	88 a
Pebulate	4 lb			
Solarization + SoilGard (<i>G. virens</i>)	8 wk drench	29 ab	76 bc	71 b

Mean separation by Duncan's new multiple range test, 5% level of significance.

Table 2. Effect of fall applied methyl bromide alternatives on control of purple nutsedge, crabgrass and pigweed in fall tomatoes.

Treatment	Rate/acre	Number of plants emerged in the bed/210 ft of row				
		Nutsedge			Crabgrass	Pigweed
		9 Sept	29 Oct	20 Nov	29 Oct	29 Oct
Nontreated	0	988 a ^a	540 a ✓	696 a	42 a ✓	18 a ✓
Methyl bromide	350 lb	5 b	6 b	10 b	1 b	0 b
1,3-D + chloropicrin + pebulate	35 gal + 4 lb a.i.	31 b	170 b ✓	221 b	2 b	1 b
Solarization + SoilGard (<i>G. virens</i>)	8 wk, drench	118 b	223 b ✓	249 b	34 a ✓	7 b

Mean separation by Duncan's new multiple range test, 5% level of significance.

Table 3. Effect of methyl bromide alternatives on rootknot nematode gall formation, numbers of nematodes in soil samples at the end of the season from the rhizosphere of tomato plants and incidence of *Fusarium* wilt. Fall 1998.

Fumigant/herbicide	Rate per acre	Rootknot gall index (0 to 8)	Nematodes (no./100 cc soil)		F. wilt incidence (%)	
			Rootknot	Sting	25 Nov	7 Dec
Nontreated	0	2.1 b ^a	300 a	11 a	30 a	39 a
Methyl bromide	350 lb	0.0 c	1 a	1 a	1 c	2 c
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	0.7 bc	63 a	2 a	1 c	2 c
Solarization + SoilGard (<i>G. virens</i>)	8 wk, drench	3.9 a	300 a	9 a	11 b	22 b

^aDuncan's new multiple range test, 5% level of significance.

was over 20% which would be unacceptable commercially. The inclusion of *G. virens* with solarization was to aid in control of *Fusarium* crown rot (*Fusarium oxysporum* Schlecht. f. sp. *radicis-lycopersici* Jarvis and Shoemaker). No crown rot was observed in this experiment. It is not believed that *G. virens* added anything to the control of *Fusarium* wilt in this experiment because it is rather specific for the crown rot organism.

Tomatoes were harvested 3 times during the season and were graded and sorted by size. Yields were fairly similar from one harvest to the next. The most 5 × 6 size and total marketable fruit were produced with methyl bromide and 1,3-D + chloropicrin + pebulate in the first two harvests and for the season total (Table 4). In the third harvest, with methyl bromide and 1,3-D, more 5 × 6 size fruit were produced than with solarization or the nontreated and more marketable fruit were produced compared to the nontreated plots. Fewer 7 × 6 size fruit were produced in the first harvest with the two fumigants, but it was greater in the second and third harvests and for the season as a whole. There was no difference in the number of 6 × 6 size fruit in the first harvest, but fumigation increased production in the second and third harvests and for the season total. Generally, soil fumigation increased cull production, indicating that overall fruit production was greater with methyl bromide and 1,3-D compared to no treatment

or soil solarization. There was no difference in fruit production in any size category or marketable or cull yields between methyl bromide and 1,3-D + chloropicrin + pebulate. Yields of all sizes and grades were greatest with the fumigant treatments, intermediate with soil solarization and lowest where no soil treatment was applied.

In an attempt to explain some of the growth differences observed between fumigation and solarization, soil samples were obtained in early Nov. for analysis of elemental composition to determine if there were fewer nutrients left in the bed in nontreated and solarization plots, perhaps as a result of nutesedge growth. Few differences were observed (data not presented). Plots treated with 1,3-D + chloropicrin + pebulate had slightly more organic matter than the other treatments and the level of K was higher than observed in the nontreated plots. Sulfur also was present in greater quantity in the 1,3-D plots than in the nontreated or in the solarized plots, most likely reflecting the difference in organic matter. The lack of significant differences in elemental analysis between fumigation with methyl bromide and soil solarization suggests that soil nutrient concentrations were not a factor in the poor growth observed with soil solarization.

Double-cropped cucumber. Cucumber stands were higher with methyl bromide than with no fumigant (Table 5). Cu-

Table 4. Effect of fall applied methyl bromide alternatives on yield of fall tomato, 1998.

Treatment	Rate/acre	Number of 25 lb. cartons per acre				
		5 × 6	6 × 6	6 × 7	Marketable	Cull
----- First Harvest -----						
Nontreated	0	280 b ^a	65 a	25 a	368 b	57 b
Methyl bromide	350 lb	663 a	54 a	4 b	721 a	103 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	606 a	61 a	4 b	667 a	134 a
Solarization + SoilGard	8 wk, drench	383 b	46 a	8 b	437 b	100 a
----- Second Harvest -----						
Nontreated	0	234 c	176 c	103 c	514 c	57 c
Methyl bromide	350 lb	970 a	621 a	330 a	1917 a	192 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	866 a	575 a	333 a	1794 a	218 a
Solarization + SoilGard	8 wk, drench	586 b	379 b	230 b	1196 b	123 b
----- Third Harvest -----						
Nontreated	0	31 b	65 c	80 c	176 c	46 c
Methyl bromide	350 lb	92 a	249 a	284 a ✓	625 a	165 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	73 a	207 ab	195 b ✓	471 ab	161 a
Solarization + SoilGard	8 wk, drench	61 ab	146 b	157 b	364 b	103 b
----- Season Total -----						
Nontreated	0	540 c	310 c	207 c	1058 c	161 c
Methyl bromide	350 lb	1729 a	920 a	621 a	3270 a ✓	460 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	1541 a	843 a	548 a	2932 a	514 a
Solarization + SoilGard	8 wk, drench	1031 b	572 b	395 b	1997 b ✓	326 b

^aMean separation by Duncan's new multiple range test, 5% level of significance.

5. Effect of fall applied methyl bromide alternatives on early emergence (11 Mar.) and vigor (23 Apr.) of spring double-cropped cucumbers, weed control in the bed, rootknot nematode galling of cucumber roots, and yield of cucumbers, 1999.

Treatment	Rate/acre	No. of plants emerged/75 ft	Vigor (%)	Weed control (no of plants./70 ft of row)				Root galling Index	Yield (Bu./acre)
				Nutsedge	Crabgrass	Pigweed	Eclipta		
Treated	0	56 b ^a	71 b	576 a	14 ab	6 a	1 a	5.9 a	980 b
Methyl bromide	350 lb	62 a	82 a	116 b	6 b	1 a	1 a	1.7 b	1597 a
1,3-D + chloropicrin	35 gal	59 ab	78 ab	106 b	6 b	3 a	1 a	4.2 ab	1289 ab
Soil solarization + SoilGard (C. vitreus)	4 lb 8 wk drench	59 ab	68 b	52 b	24 a	4 a	2 a	6.3 a	826 b

^a Separation by Duncan's new multiple range test, 5% level of significance.

iber plant vigor was greater with methyl bromide than soil solarization or no soil treatment but was not different from that observed with 1,3-D + chloropicrin + pebulate. Solarization did not improve vigor relative to the nontreated control.

Even though all of the nutsedge were desicated with aquat after the final tomato harvest and again shortly before seeding cucumbers, by Apr., nutsedge was once again present in all plots but with no difference in numbers emerged through the plastic with either fumigant treatment with solarization (Table 5). Interestingly, the number of sedge plants had increased in methyl bromide treated plots compared to what was observed during the fall tomato crop, indicating that the nutsedge population already was beginning to rebound and demonstrating that even with methyl bromide, it is not a case of nutsedge eradication but rather nutsedge management. Significantly more crabgrass was present in the beds of solarization plots than in fumigated plots, but there were no differences in populations of pigweed or eclipta [*Eclipta alba* (L.) Hassk.].

The extent of root galling by rootknot nematodes was assessed visually after the last harvest (Table 5). There was considerable galling on the cucumber roots in this experiment and there was some variation in the extent among replicates as well as treatments. Methyl bromide was the only treatment to significantly reduce gall formation relative to the nontreated control treatment. The degree of galling with soil solarization was the same as that with no fumigant, whereas 1,3-D was intermediate between methyl bromide and solarization, i.e., not significantly different from either.

Cucumbers were harvested 8 times during the spring season. Fruit yields with methyl bromide applied the previous fall were greater than with solarization or no soil treatment (Table 5). Cucumber production in solarized plots was equal to the nontreated. Production of slicer cucumbers in soil treated

in the fall with 1,3-D + chloropicrin + pebulate was not significantly different from that observed with methyl bromide or solarization, indicating that the 1,3-D treatment was intermediate. The average weight of an individual cucumber was not affected by treatment (data not presented).

Millet cover crop. Fall soil treatment affected the growth of millet as a cover crop the following spring and the growth of weeds (Table 6). Millet canopy coverage was reduced where no fumigant was applied or soil solarization was practiced. Millet was taller in soil fumigated with methyl bromide or 1,3-D + chloropicrin with pebulate herbicide than in the nontreated soil. Methyl bromide also produced taller millet than was observed in solarized plots, whereas 1,3-D was intermediate between the two treatments. There was no difference in fresh weight of millet among the treatments; however, crabgrass was difficult to separate from millet once cut and some of the weight recorded in solarized and nontreated plots may have been due to crabgrass and not millet. Nutsedge population was not affected by fall treatment nor was pigweed, but there was significantly less crabgrass in plots which were treated with fumigant in the fall as compared to solarization or nontreatment, suggesting that this reduction was the result of the improved growth of millet in the fumigant plots as indicated by millet canopy estimates.

Results of these studies indicate that 1,3-D + chloropicrin + pebulate can provide broadspectrum pest control in fall tomato comparable to that obtained with methyl bromide. Purple nutsedge control can be challenging, but the addition of pebulate overcomes the short comings of 1,3-D + chloropicrin, as has been demonstrated in previous research (Gilreath et al., 1994). Resurgence of rootknot nematodes was a problem with all treatments, but it was especially troublesome with solarization. Fumigation with 1,3-D + chloropicrin controlled rootknot nematodes for the tomato crop, but the extent of root galling increased during the cucumber crop. Soil solar-

6. Effect of fall applied methyl bromide alternatives on growth of a brown top millet cover crop and weeds in the millet in the following spring.

Treatment	Rate/acre	Millet				Control (%)	
		Canopy (%)	Height (inches)	Fresh wt (tons/acre)	Nutsedge no./5.5 ft ²	Crabgrass	Pigweed
Nontreated	0	28 b ^a	21 c	6.8 a	6 a	58 a	10 a
Methyl bromide	350 lb	76 a	32 a	6.9 a	0 a	18 b	6 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	61 a	30 ab	7.7 a	7 a	21 b	11 a
Soil solarization + SoilGard (C. vitreus)	8 wk, drench	32 b	25 bc	7.1 a	1 a	69 a	8 a

^a Separation by Duncan's new multiple range test, 5% level of significance.

tion did not perform well in this study for either the fall natto crop or the spring double cropped cucumbers. Considerable variation in results existed among replications for treatments, but this was especially true with solarization. This serves to point out the highly variable nature of solarization as an alternative to methyl bromide and the need for more research to elucidate those variables which are responsible for this erratic performance and to identify ways of enhancing performance of soil solarization under Florida conditions. Performance of spring cover crops, such as millet, so may be affected by the soilborne pest control program employed the previous fall, as evidenced by the growth performance of millet in this study. Not only did the fall fumigation program impact millet growth, but indirectly through the effect of millet growth on weed emergence and growth, it reduced a noticeable effect on weed control in the spring millet crop. The interrelationship of soilborne pests and cropping and soil fumigation practices is a complex one. It is becoming apparent that any one practice can produce effects which span beyond the present crop into near term future crops. The loss of methyl bromide will serve to expand our knowledge of these relationships.

Literature Cited

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ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: metam-Na

[Insert Alternative]

Study: Strawberry production with alternatives to methyl bromide

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted _____

1b. Township caps _____

1c. Alternative not acceptable in consuming country _____

1d. Other (Please describe) _____

X

This alternative can be used in tomato, strawberry, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide****Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website?

Yes _____

No _____

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Locascio, Olson, Chase, Sinclair, Dickson, Mitchell
and Chellemi

3. Publication and Date of Publication

Proc. of 1999 Annual International Research Conf. on Methyl
Bromide Alternatives, 1999

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

metam-Na

6. Was crop yield measured in the study?

Yes X

No _____

7. Describe the effectiveness of the alternative in controlling pests in the study.

Similar results (not effective) would be expected in North Carolina in
control of yellow nutsedge by this alternative. Effectiveness was not
acceptable for control.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Similar results would be expected in North Carolina across strawberry, tomato,
cucurbit crops and pepper. Growers do not have access to a rotovator for
incorporating this alternative.

Research Summary Table

Alternative: Metam-NaStudy: Locascio et al., 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number List the treatment number from the research study you are citing.

Col. B: Treatment List what type of pest control method was used.

Col. C: Rate Enter the pounds or gallons of a chemical used, days of solarization, etc.

Col. D, F, H, J, L, N: Interval Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).

Cols. E, G, I, K, M, O: Rating for Interval: Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.

Control of Pests 1 and 2 (Cols. D - I and Cols. J - O): For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).

Col. J: Yield Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (no. per m ²) (penetrating plastic)						Pest 2: Nutsedge (no. per m ²) (penetrating plastic)						Yield (flats/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	untreated		6 wks	22					6 wks	16					1,705
2	methyl bromide +														
	chloropicrin	347	6 wks	0					6 wks	0.9					4,131
6	metam-Na	32 gal	6 wks	28					6 wks	14					2,552

Comments:

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by th user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
metam-Na	nutsedge	metam-Na	4.26	136	32	gal	\$ 4.00	\$ 15.00	75	100	1	\$ 218.00
Non-Chemical Pest Control	Target Pests	Description										Cost/area
Total												\$ 218.00

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments:

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25.00			15.00 per acre	Tractor with a tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

03-0041

1999

Annual
International Research
Conference
On
Methyl Bromide
Alternatives
And Emissions Reductions

November 1 – 4, 1999

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STRAWBERRY PRODUCTION WITH ALTERNATIVES TO METHYL BROMIDE FUMIGATION

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Strawberries were transplanted in the fall of 1997 to polyethylene mulched beds in Gainesville on a Millhopper fine sand and in Quincy on an Orangeburg fine sandy loam to evaluate the effects of soil fumigants and solarization on fruit production and reported (Locascio, et al., 1999). Fumigant and solarization treatments were applied on Aug. 21 and 19, 1997, respectively. On selected plots, napropamide was applied at 4.8 kg/ha for weed control and fumigant metam-Na at 300 L/ha were rototilled into the bed. Soil fumigants were injected with two chisels per bed spaced 30 cm apart at a depth of 20 to 25 cm at 390 kg/ha 67 % MBr + 33 % Pic, 340 kg/ha Pic, 327 L/ha a C-17, and C-35, and 440 kg/ha dazomet. Drip tubing was placed on the beds before application of 38.1 μ m (1.5 mil) black polyethylene mulch or 102 μ m (4 mil) clear thermal infrared-absorbing film (AT Plastics, Inc., Edmonton, Canada). Soil temperature was measured at 0- to 25-cm depths in two plots mulched with black and in four plots mulched with the clear film (Chase et al., 1997). Some clear mulches (Table 1) were painted with black latex paint a week before transplanting. 'Chandler' was transplants on Oct.21 and Nov.7, respectively.

Transplants were sampled for fungal colonization of roots on 24 Oct. Fruits were harvested twice weekly, graded and weighed. Soil and plants were sampled for nematode and fungal populations at Gainesville at the end of the harvest season on May 18.

Fungi were isolated from the roots and crown tissue of every plant sampled before transplanting. VA mycorrhizal fungi were observed on 95% of the root samples. *Alternaria*, *Fusarium*, *Rhizoctonia*, *Trichoderma*, and an unknown pycnidial forming fungus were isolated from 5, 35, 25, 5, and 5% of the crown pieces, respectively. Although some species of *Alternaria*, *Fusarium*, and *Rhizoctonia* may cause root diseases, it was not possible to determine the source of pathogens isolated from roots during the growing season and at harvest.

Solar radiation and soil temperatures decreased over the measurement periods (60 days) from Aug. to Oct. Soil temperatures by late Sept. were insufficient to control nutsedge tubers or to kill emerged shoots trapped under the clear film. Maximum soil temperatures exceeding 45 C with the clear mulch at 10 cm occurred on less than 2 % of the days. By the sixth week of solarization at Gainesville, nutsedge density in the control treatment was 22 plants m⁻² (Table 1). Metam-Na + napropamide was the only treatment that failed to reduce the number of nutsedge plants penetrating the mulches. All other treatments significantly reduced nutsedge densities to levels that were statistically similar to that

with MBr-Pic. By Dec., it was apparent that painting the solarization film before transplanting was necessary. The clear film maintained soil temperatures that were sufficiently warm to promote the sprouting of tubers but not hot enough to cause foliar scorching of the shoots trapped under the film. The cooler temperatures apparently induced nutsedge dormancy since the nutsedge pressure was relatively low with all other treatments. By the end of the crop, nutsedge densities under the solarization films were greater than with the black films (Table 1).

At Gainesville, strawberry plant growth was slow, possibly due to the high occurrence of rainfall after transplanting. Rainfall exceeded average in each month from transplanting through Mar. Rainfall in Feb. was approximately three times the average. Plant vigor ratings were made on Jan. 29, 1998 (Table 1). Plant growth rating of plants with no treatment was only 2.5 on a rating of 1 (poor growth) to 10 (excellent growth) and was significantly greater with all treatments except that with the unpainted clear mulch solarization treatment. Marketable fruit yields were significantly higher with MBr-Pic than with no fumigant, metam-Na with and without Pic, and with the soil solarization treatment-mulch painted black before transplanting (Table 1). Total fruit yields in flats/ha were highest with MBr-Pic (4,131), C-17 (3,620), C-35 (3,541), Pic (3,311), and soil solarization with metam-Na-mulch painted (3,002), and significantly lower with metam-Na (2,552), soil solarization-mulch painted (2,710), metam-Na + Pic (2,199) and the check (1,705). Fruit was not obtained with soil solarization-clear mulch not painted. Weed growth under the clear mulch was extensive and picked the mulch up 7.5 to 15 cm over the soil; thus, strawberry plants did not survive the weed competition.

At Quincy, strawberry plant growth was excellent and fruit yields are shown in Table 2. Total fruit yield (in flats/ha) was highest with Pic (4,040), MBr-Pic (3,511), C-35 (3,553), C-17 (3,333), Metam-Na + Pic (3,279), Dazomet (3,620), and Dazomet + solarization-mulch painted (3,543). Lower yields were obtained with solarization-mulch painted (3,210) and with metam-Na + Pic (3,116) and with no fumigant (2,417). The lowest yield was obtained with solarization-mulch not painted (815). Fruit size response to fumigant treatment was similar to that obtained for total yield. Marketable fruit were larger with treatments that resulted in higher yield and smaller with treatments that resulted in lower yields. Nutsedge counts were made on Sept. 30 and data are shown in Table 2. Nutsedge control was excellent with MBr-Pic, and with all solarization treatments, intermediate with C-17 and C-35 + napropamide, and poorest with Pic, metam-Na-Pic and dazomet each + napropamide and with the untreated check.

Roots and crowns of strawberry plants in all soil treatments at the end of the season were colonized by a wide array and diversity of fungi, and high incidences of colonization were attained by many of them. Fungi in 18 genera were isolated from roots. Incidences of infection of plants by potentially damaging pathogenic fungi included 29-59% with *Alternaria* spp., 13-42% with *Sclerotium rolfsii*, 50-83% with *Colletotrichum* spp., 13-59% with *Curvularia* spp., 75-96% with *Fusarium oxysporum*, 4-17% with *Macrophomina phaseolina*, 29-79% with *Phoma* spp., 17-42% with *Pythium aphanidermatum*, 4-17% with other *Pythium* spp., and 67-92% with *Rhizoctonia solani*.

Table 1. Effect of fumigant treatments on fruit yield, plant vigor, and nutsedge counts of 'Chandler' strawberries. Gainesville, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Plant vigor ^v (Jan 29)	Nutsedge (plants/m ²)		
				Through film film Oct 8 May 18	Under May 18	
1 Untreated		1705 d ^w	2.5 d	21.5 a	8.5	16.1 bc
2 Methyl bromide /Pic (67/33)	390 kg	4131 a	10.0 a	0.0 b	0.0	0.9 c
3 Chloropicrin (Pic) ^z	340 kg	3311 abc	6.8 bc	5.0 b	4.5	1.3 c
4 1,3-D + 35 % Pic ^z	327 L	3541 ab	8.0 b	3.4 b	0.9	4.0 c
5 1,3-D + 17 % Pic ^z	327 L	3620 ab	6.8 bc	0.8 b	20.2	16.6 bc
6 Metam-Na ^z	300 L	2552 bcd	5.5 c	28.4 b	12.1	13.9 bc
7 Metam-Na + Pic ^z	300 L + 170 kg	2199 cd	4.8 c	5.0 b	1.3	6.3 c
8 Solarization ^x		---	1.0 d	0.0 b	0.0	45.7 ab
9 Solarization ^y		2710 bcd	5.5 c	0.4 b	0.0	49.3 a
10 Metam-Na + Pic + solarization ^y	300 L + 170 kg	3002 abcd	6.0 bc	0.0 b	0.5	44.8 ab

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear and due to excessive weed growth, fruit was not harvested.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^v Plant vigor ratings with 10 = maximum growth and 1 = 10 % of maximum growth.

Table 2. Effect of fumigant treatments on yield, fruit weight, and nutsedge counts of 'Chandler' strawberries. NFREC, Quincy, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Size (g/fruit)	Nutsedge (plants/m ²) ^y
Untreated		2417 c ^w	15.5 c	29.3 ab
Methyl bromide /Pic (67/33)	390 kg	3511 ab	17.0 ab	1.0 d
Chloropicrin (Pic) ^z	340 kg	4040 a	17.4 ab	20.2 abc
1,3-D + 35 % Pic ^z	327 L	3553 ab	17.1 ab	10.1 cd
1,3-D + 17 % Pic ^z	327 L	3333 ab	17.2 ab	13.2 bcd
Metam-Na + Pic ^z	300 L + 170 kg	3279 ab	16.9 abc	19.8 abc
Metam-Na ^z	300 L	2933 bc	16.1 bc	30.4 a
Dazomet ^z	440 kg	3620 ab	17.1 ab	33.7 a
Solarization ^x		815 d	13.4 d	0.1 d
Solarization ^y		3210 b	16.2 abc	0.2 d
Metam-Na + Pic + solarization ^y	300 L + 170 kg	3116 bc	16.1 bc	0.1 d
Dazomet +solarization ^y	440 kg	3543 ab	17.7 a	0.1 d

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^y Nutsedge shoots penetrating mulch counted on Sept. 30.

In general, the high incidence of pathogenic fungi, especially *S. rolfii*, *F. oxysporum*, *P. aphanidermatum*, and *R. solani*, and the severity of root disease caused by them undoubtedly contributed to poor plant growth, early plant mortality, and low yields at Gainesville. Fumigation probably delay the time of infection by fungi dispersed into treated soil and allowed increased yields before pathogenic fungi reach high levels of colonization and cause severe disease.

The population densities of the highly pathogenic sting (*Belonolaimus longicaudatus*) nematode at the end of the season at Gainesville was low and not affected by treatment (data not shown).

In summary, early plant growth and yields at Gainesville were poorer than expected, probably due the high incidences of fungal root diseases and to excessive rainfall during Dec. to Mar. The yield with MBr-Pic was statistically similar to that with 1,3-dichloropropene + 17% Pic (C-17), C-35, Pic, and soil solarization + metam-Na-mulch painted black before transplanting. Yields were significantly lower with the check, metam Na, metam Na + Pic, and soil solarization-mulch painted before planting than with MBr-Pic. At Quincy, plant growth was excellent and yields were statistically similar with Pic, MBr-Pic (67:33), dazomet, solarization + dazomet-mulch painted black, C-17, C35, and metam-Na + Pic. Lowest yields were obtained with the untreated check and solarization-mulch not painted black before planting. Soil solarization with the mulch painted black suppressed nutsedge but regrowth occurred with the mulch left clear. At Gainesville, treatment had no effect on sting nematode (*Belonolaimus longicaudatus*) population densities extracted from soil samples or fungi populations on plant roots at the end of the season.

Literature Cited

- Chase, C.A., T. R. Sinclair, S.J. Locascio, J.P. Gilreath, J.P. Jones, and D.W. Dickson. 1997. An evaluation of improved polyethylene films for cool-season soil solarization. Proc. Fla. State Hort. Soc. 110:326-329.
- Locascio, S. J., S. M. Olson, C. A. Chase, T. R. Sinclair, D. W. Dickson, D. J. Mitchell, and D. O. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Proc. National Agric. Plastics Congress. 28:148-154.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + chloropicrin + pebulate

[Insert Alternative]

Study: Effect of methyl bromide, 1,3-D + chloropicrin with pebulate and soil

[Insert Study Title] solarization.....

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

Pebulate is labeled only in tomato not other vegetable crops. It is expected that 1,3-D + chloropicrin in other crops (cucurbits, strawberry and pepper) would give less control of purple nutsedge because pebulate has nutsedge activity and not be used in other crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide****Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website?

Yes _____

No _____

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Gilreath, Noling, Locascio and Chellemi

3. Publication and Date of Publication

Proc. Florida State Hort. Soc., 1999

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

1,3-Dichloropropene + chloropicrin with pebulate and soil solarization on
soilborne pest control in tomato followed by double cropped cucumber.

6. Was crop yield measured in the study?

Yes X

No _____

tomato

7. Describe the effectiveness of the alternative in controlling pests in the study.

This alternative was inconsistent. Good control sometimes unacceptable at
other times during the growing season.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

This alternative would give less control in North Carolina because of our
more extreme weather in our state. Also pebulate is not registered in pepper,
cucurbit crops and strawberry. Also in tomato, we often observe injury from
this herbicide.

Research Summary Table

Alternative: 1,3-D + Chloropicrin + PebulateStudy: Glireath, Noling, Locascio and Chellemi, 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. al per area)	Pest 1: Purple Nutsedge (no. per 210 ft. row)						Pest 2						Marketable Tomato Yield (boxes/acre)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		42 DAT	540											1,058
2	67/33 methyl bromide	350 lbs.	42 DAT	6											3,270
3	1,3-D + chloropicrin +	35 gal													
	pebulate	4 lbs. al	42 DAT	170											2,932.0

Comments: DAT = days after tomato transplanting; yield is of tomato; yield reported in 25 lb. boxes/acre; without use of pebulate (not registered in pepper) nutsedge control would be lower.

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
1,3-D /	nutsedge	1,3-D	83%									
chloropicrin		chloropicrin	17%		35 gal	gal	\$ 13.10	\$ 75.00	80	100%		\$ 813.50
pebulate			6 lbs./gal	4	5.3 pt	pt	\$ 33.13	\$ 20.00		100%		\$ 33.13
Non-Chemical Pest Control	Target Pests	Description										Cost/area
Hand removal	nutsedge	Hand removal would be impossible. I would estimate over \$2,000 per acre to hand remove nutsedge.										
Comments:											Total	\$ 648.63

03-0041

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 pounds)	2,932.00	\$ 6.50	\$ 19,058.00
				Total Revenue	\$ 19,058.00

Comments:

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

1,3-D + Chloropicrin + Pebulate

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling with Tillovator	25.00			15.00 per acre	Tractor + tillovator
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments: Most growers in North Carolina do not a tillovator.

Vegetable Section

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Proc. Fla. State Hort. Soc. 112:292-297. 1999.

EFFECT OF METHYL BROMIDE, 1,3-DICHLOROPROPENE + CHLOROPICRIN WITH PEBULATE AND SOIL SOLARIZATION ON SOILBORNE PEST CONTROL IN TOMATO FOLLOWED BY DOUBLE-CROPPED CUCUMBER

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Additional index words. Soil fumigant, weed control, purple sedge, Tillam, Telone C-17, root knot nematode, Fusarium wilt.

Abstract. Soil fumigation with 1,3-dichloropropene (1,3-D) + chloropicrin (Telone C-17) with pebulate (Tillam) and soil solarization + *Gliocladium virens* (SoilGard™) were compared to fumigation with methyl bromide for control of soilborne pests and crop response for fall tomatoes (*Lycopersicon esculentum* Mill.) and double-cropped spring cucumbers (*Cucumis sativus* L.) in 1998-99. Soil treatments were applied prior to the fall tomato crop and soil solarization was conducted for 6 weeks pre-plant. *G. virens* was applied to the tomato plants drench in the setting water at transplanting. The combination of pebulate and 1,3-D + chloropicrin provided nutsedge (*Sclerotium rotundus* L.), Fusarium wilt (race 3, incited by *Fusarium oxysporum* f.sp. *lycopersici*) and root knot nematode (*Meloidogyne* spp.) control and tomato yields similar to that obtained with methyl bromide, but soil solarization did not. Solarization, 1,3-D + chloropicrin + pebulate and methyl bromide provided statistically similar control of nutsedge, although a wide spread numerical difference occurred between methyl bromide and the other two treatments, but there was a crabgrass in solarized plots than in those which received one of the two fumigants. Root gall formation on tomato due to root knot nematodes was worse with solarization than with other treatment, including the nontreated control and the fumigant. Fusarium wilt was intermediate between that of fumigants and the nontreated. Tomato fruit production

with 1,3-D + chloropicrin + pebulate was equal to that with methyl bromide, but solarization resulted in fewer fruit in each size grade and total marketable yield. Tomato production with soil solarization + *G. virens* drench was only slightly higher than that obtained without fumigation. When cucumbers were grown as a double crop in the spring following fall tomatoes, yields were similar with 1,3-D + chloropicrin + pebulate and methyl bromide. Solarization + *G. virens* drench reduced cucumber yield relative to methyl bromide but was similar to that of 1,3-D + chloropicrin + pebulate. Root knot nematode galling of second crop cucumber, was similar with soil solarization, 1,3-D + chloropicrin + pebulate, and no fumigant. Gall formation was not significantly different between methyl bromide and 1,3-D + chloropicrin + pebulate, whereas methyl bromide greatly reduced gall severity compared to solarization. Methyl bromide improved millet growth in the spring following fall application compared to solarization or no treatment, but was not different with 1,3-D + chloropicrin + pebulate. Fewer crabgrass plants were present in millet grown in soil treated with either methyl bromide or 1,3-D + chloropicrin + pebulate than with no fumigant or with soil solarization.

Methyl bromide combined with chloropicrin for soil fumigation has been the mainstay of the mulched vegetable production system in Florida for many years (Overman and Jones, 1984). The impending loss of methyl bromide as a soil fumigant has resulted in considerable research into alternatives, both chemical and nonchemical (Gilreath et al., 1994; Locascio et al., 1997; Jones et al., 1995; Chase et al., 1997a, b; Chellemi et al., 1997). Previous research has demonstrated the efficacy of 1,3-D + chloropicrin when combined with pebulate as an alternative package for soil fumigation in tomato production (Gilreath et al., 1994; Locascio et al., 1997; Gilreath et al., 1997). In most cases, this combination has resulted in tomato yields similar to those achieved with methyl bromide. Soil solarization has provided good nutsedge control when used during the summer months and has been proposed as an alternative to methyl bromide (Chase et al., 1997a, b; Chellemi et al., 1997). Most of the research conducted to date has focused on the effects of alternatives on a first crop, mostly tomato, and little work has addressed the residual effects on a double-crop, such as cucumber. No one has investigated potential effects of fall fumigation on spring cover cropping practices.

The purpose of this research was to compare standard methyl bromide soil fumigation to fumigation with the best chemical alternative, a mixture of 1,3-dichloropropene (1,3-D) and chloropicrin used in combination with pebulate, and the best nonchemical alternative, soil solarization combined with a plant drench of a commercial preparation of *Gliocladium virens* (SoilGard, Thermo Trilogy Corp.), for soilborne pest control and crop response in both fall tomatoes and spring double-cropped cucumbers and to determine any ef-

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these fall treatments may have on a spring planted millet crop.

Material and Methods

The experiment was conducted at the Gulf Coast Research and Education Center in Bradenton, FL on an Eau Gallie sand soil during the fall of 1998 and the spring of 1999. Subsurface irrigation was applied during the summer irrigation period and the first half of the tomato crop then remainder of the tomato crop and all of the spring cucumber crop was irrigated with drip irrigation. Treatments were assigned to 3 bed plots 210 ft in length arranged in a randomized complete block design and replicated 6 times. Beds were spaced 5 ft apart on centers and were 30 inches wide and 8 inches high. Plots were subdivided into three 70 ft long subplots for spring treatments. Treatments consisted of a nontreated control, methyl bromide and chloropicrin (67/33%, respectively) at 350 lbs./acre, 35 gal/acre of a mixture of 1,3-D and chloropicrin (83/17%, respectively) with pebulate herder (4 lb/acre) applied prior to fumigant application), 8 weeks of soil solarization combined with *G. vires* as a pre-drench (1 lb/100 gal) the day after transplanting. Soil solarization began on 28 July 1998 and ended on 15 Sept. 1998. A 1.25 mil thick, clear polyethylene mulch film was applied white with latex paint, using a minimum of 3 coats to reduce transmission of long wave radiation of the clear polyethylene film. Starter fertilizer (50, 22, 42 lb of N, P and K, respectively) was broadcast on the fields in the solarization plot areas just prior to preparation of the beds and was incorporated with a s-tine harrow. Starter fertilizer was applied in the same fashion to the areas for the other treatments prior to application of pebulate. Pebulate was applied to soil surface pre-bed in 29 gal/acre of spray preparation by a tractor mounted sprayer and incorporated 6 to 8 inches deep in one pass with a s-tine harrow (field cultivator) on 3 Aug. 1998. Beds were formed on 5 Aug. 1998 and methyl bromide and 1,3-D/chloropicrin were applied that day with a standard pressurized fumigation rig on a superbedder equipped with 3 chisels per bed spaced 12 inches apart. Fumigant flow was controlled by a flow meter which was calibrated to deliver the specified quantity of fumigant about 2 inches above the bottom of the finished bed. Fertilizer (150 and 173 lb/acre of N and K, respectively) was applied in two bands either side of the bed surface, 10 inches from the bed center. Drip tubing was applied to the bed center and the beds were covered with white on black high density polyethylene immediately following the fumigant application. Seven days preplant, all solarization and nontreated control plots were sprayed with paraquat (0.5 lb/acre) to desiccate existing weeds and cover (primarily purple nutsedge) so it would not interfere with early plant growth. Methyl bromide and 1,3-D treatments were not sprayed because no nutsedge had emerged. Two week-old 'Solimar' tomato plants were transplanted 2 ft apart into the beds on 17 and 18 Sept 1998. Plants received a drench of dactoprid in the transplant water to control silverleaf. Plants were sprayed with fungicide weekly to protect against foliar diseases and insecticides were applied on an as needed basis. Fertigation began about 4 weeks before the first harvest and 1.5 lb/acre of N was applied daily for the remainder of the season. Purple nutsedge (*Cyperus rotundus* L.) plants were counted on 9 Sept., 29 Oct. and 20 Nov. 1998. Pigweed and crab-

grass, the two other weeds present with sufficient uniformity, were counted 29 Oct. 1998. Survival of tomato plants was determined on 13 Oct. 1998 by counting the number of plants per subplot and tomato plant vigor was evaluated twice (13 Oct. and 12 Nov. 1998) using a percentage visual assessment scale where 100% represented optimum plant vigor and 0 indicated the plants were dead. Soil samples were collected from each plot on 6 Nov. 1998 and were sent to a commercial lab for soil mineral analysis to determine if there were any differences in nutritional status of the soil at midseason. Additional soil samples were collected twice during the tomato crop and composition of the soil microflora and fauna was determined by counting colonies on dilution plates of diagnostic media. Soil samples for nematode analysis were collected from the rhizosphere of tomato plants at the time of the last harvest and the nematodes were separated from 100 cc of soil by using a standard sieving and centrifugation procedure (Jenkins, 1964). The numbers of rootknot (*Meloidogyne* spp.) and sting (*Belonolaimus* spp.) nematodes were counted. The crowns and associated roots of 5 tomato plants were dug from each plot and the severity of rootknot nematode gall formation was evaluated using a 0 to 8 rating scale where 0 represented no galls present and 8 indicated plants which were severely galled. The number of tomato plants infested with Fusarium wilt (race 3, incited by *Fusarium oxysporum* f. sp. *lycopersici*) from each 32 plant subplot was counted on 25 Nov. and 7 Dec. 1998 and the numbers were expressed as a percentage of the actual number of plants originally in each plot. Tomatoes were harvested 3 times (1, 14 and 29 Dec. 1998). Fruit were manually separated into marketable and cull categories then marketable fruit were sorted by size into the standard extra large (5×6), large (6×6) and medium (6×7) size grades and weighed. At the end of the season, all tomato plants and weeds were sprayed with a foliar application of paraquat (1 lb/acre) using a boom sprayer with drops fitted with 4 nozzles per bed to kill the tomatoes and the weeds. The tying twine, stakes and polyethylene mulch were left in the field and a second application of paraquat was made to all plots two weeks before planting cucumbers in the spring.

Double-cropped cucumber. 'Competitor' cucumbers were direct seeded into the beds in hills spaced 2 ft apart (3 seed per hole, thinned to 1 plant per hole) in the first 70 ft-long subplot of each main plot on 18 Feb. 1999. The crop was grown using drip irrigation delivering an average of 1.5 lb N/acre per day. Fungicide was applied weekly while insecticide was applied as needed. Early emergence of cucumbers was determined by counting the number of plants on 11 March 1999 and cucumber plant vigor was evaluated on 23 Apr. The number of weeds of the principal weed species were counted on 13 Apr. 1999. The degree of galling due to rootknot nematodes was determined on 25 May 1999 after the last harvest by inspecting the roots and crowns of five cucumber plants in each plot and visually assessing the extent of damage using the aforementioned 0 to 8 rating scale. Cucumbers were harvested eight times from 20 Apr. through 14 May 1999 and the number and weight of marketable fruit were determined.

Millet cover crop. 'Brown top' millet was planted in one subplot per main plot on 22 Mar. 1999. The millet was allowed to grow using only residual fertilizer from the fall tomato crop. Some irrigation in the form of subsurface irrigation was supplied to the millet during the course of the spring. No pesticides were applied to the cover crop. Once millet seed had begun to set, a 5.5 ft² sample area was selected randomly with-

each millet plot and the number of weeds by species were counted within this area. Millet plant height was measured. Canopy coverage was estimated visually, and the fresh weight of millet plants was determined on 25 May 1999.

Results and Discussion

Fall tomato. Early season establishment and survival of tomato plants, as measured by plant stand, was better with methyl bromide and 1,3-D treatments than in the nontreated plots (Table 1). Early survival of tomato plants with soil solarization was similar to that in the nontreated plots. Tomato plants were more vigorous in soil treated with methyl bromide and 1,3-D + chloropicrin + pebulate than in soil which received no chemical treatment. Fumigation with methyl bromide was superior to soil solarization at both evaluation dates. The combination of 1,3-D + chloropicrin + pebulate improved tomato plant vigor over what was observed with soil solarization at the second evaluation in November. Plant vigor was similar with soil solarization and no treatment.

By early Sept. before transplanting, nutsedge had begun to emerge and penetrate the mulch in all of the plots (Table 1). There were fewer nutsedge plants in all treated plots than in the nontreated plots at this time. Even though the number of emerged nutsedge plants in the solarization plots was statistically less than that observed in the nontreated control plots, both the nontreated and the solarization plots were sprayed with paraquat to eliminate a large number of existing nutsedge so it would not interfere with transplanting operations and to give tomato plants a chance to become established. As a result, subsequent observations on nutsedge populations in the nontreated and soil solarization plots were skewed to the low side by the fact that all of the nutsedge in these plots was sprayed whereas the methyl bromide and 1,3-

D plots did not receive paraquat. Thus, there was a decrease in the number of emerged nutsedge plants in the nontreated plots from the time of the first count in early Sept. to the second one in late Oct. Both fumigants and soil solarization reduced nutsedge compared to the nontreated throughout the season and there was no statistically significant differences in the number of nutsedge plants between either fumigant or between the fumigants and soil solarization. There was considerable variation in nutsedge populations among the fields used in this study and this, no doubt, impacted the analysis of variance and results. Numerically, there was more nutsedge in 1,3-D plots and soil solarization than in methyl bromide treated areas. The poor control obtained with 1,3-D + chloropicrin + pebulate may be due to the fact that the soil was not overly moist at the time of application of pebulate and it dried even further as a result of aeration due to herbicide incorporation with an s-tine harrow. Bed preparation was delayed in order to bring the moisture back up so the soil would form a good bed and fumigation would improve. Pigweed (*Amaranthus hybridus* L.) control was good with all treatments relative to the nontreated, but only the fumigant treatments reduced crabgrass (*Digitaria ciliaris* (Retz.) Koel.). Crabgrass was observed growing in many plant holes in the mulch in the solarized plots and in the nontreated areas. Even with a heavy coating of latex paint on the clear plastic, considerable crabgrass and nutsedge were growing under the mulch and in places the film was not touching the soil due to this growth.

After the final tomato harvest (Table 3), the most severe root galling was observed with soil solarization. The extent of galling was not severe in the test but was much higher with solarization than occurred with any other treatment, including the nontreated control. Methyl bromide resulted in no gall formation while plants grown in soil treated with 1,3-D had a slight amount of galling which was not statistically different from either that observed on the nontreated plants or the methyl bromide plants. There was no significant difference among treatments in the number of rootknot or sting nematodes recovered from soil samples at this time, reflecting some variability among replications used in this experiment.

Fusarium wilt was present in the tomato plants. At the end of the season, about 38% of the plants in the nontreated plots displayed symptoms of infestation with *Fusarium* wilt (Table 3). The relative ranking of treatments did not change from the first evaluation on 25 Nov. to the last on 7 Dec., but the number of plants infested increased for each treatment. Soil fumigation with either methyl bromide or 1,3-D resulted in few tomato plants with symptoms of *Fusarium* wilt and both fumigants were superior to either soil solarization + *G. vires* or the nontreated control in reduction of the incidence of *Fusarium* wilt of tomato. Soil solarization + *G. vires* reduced the incidence compared with no treatment but the level of infestation

Table 1. Effect of fall applied methyl bromide alternatives on early season tomato plant stand and plant vigor, Fall 1998.

Treatment	Rate/acre	Plant stand (No./subplot)	Plant vigor (%)	
			13 Oct	12 Nov
Nontreated	0	26 b ^a	60 c	67 b
Methyl bromide	950 lb	32 a	94 a	93 a
1,3-D + chloropicrin + pebulate	35 gal	32 a	90 ab	88 a
1,3-D + chloropicrin + pebulate	4 lb			
Solarization + SoilGard (G. vires)	8 wk drench	29 ab	76 bc	71 b

Mean separation by Duncan's new multiple range test, 5% level of significance.

Table 2. Effect of fall applied methyl bromide alternatives on control of purple nutsedge, crabgrass and pigweed in fall tomatoes.

Treatment	Rate/acre	Number of plants emerged in the bed/210 ft of row				
		Nutsedge			Crabgrass	Pigweed
		9 Sept	29 Oct	20 Nov	29 Oct	29 Oct
Nontreated	0	988 a ^a	540 a ✓	696 a	42 a ✓	18 a ✓
Methyl bromide	950 lb	5 b	6 b	10 b	1 b	0 b
1,3-D + chloropicrin + pebulate	35 gal + 4 lb a.i.	31 b	170 b ✓	221 b	2 b	1 b
Solarization + SoilGard (G. vires)	8 wk, drench	118 b	228 b ✓	249 b	34 a ✓	7 b

Mean separation by Duncan's new multiple range test, 5% level of significance.

Table 3. Effect of methyl bromide alternatives on rootknot nematode gal. formation, numbers of nematodes in soil samples at the end of the season from the rhizosphere of tomato plants and incidence of *Fusarium* wilt. Fall 1998.

Fumigant/herbicide	Rate per acre	Rootknot gall index (0 to 8)	Nematodes (no./100 cc soil)		F. wilt incidence (%)	
			Rootknot	String	25 Nov	7 Dec
Nontreated	0	2.1 b	300 a	11 a	30 a	39 a
Methyl bromide	350 lb	0.0 c	1 a	1 a	1 c	2 c
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	0.7 bc	63 a	2 a	1 c	2 c
Solarization + SoilGard (<i>G. virens</i>)	8 wk, drench	3.9 a	300 a	9 a	11 b	22 b

*Duncan's new multiple range test, 5% level of significance.

was over 20% which would be unacceptable commercially. The inclusion of *G. virens* with solarization was to aid in control of *Fusarium* crown rot (*Fusarium oxysporum* Schlecht. f. sp. *radicis-hypocrepis* Jarvis and Shoemaker). No crown rot was observed in this experiment. It is not believed that *G. virens* added anything to the control of *Fusarium* wilt in this experiment because it is rather specific for the crown rot organism.

Tomatoes were harvested 3 times during the season and were graded and sorted by size. Yields were fairly similar from one harvest to the next. The most 5 × 6 size and total marketable fruit were produced with methyl bromide and 1,3-D + chloropicrin + pebulate in the first two harvests and for the season total (Table 4). In the third harvest, with methyl bromide and 1,3-D, more 5 × 6 size fruit were produced than with solarization or the nontreated and more marketable fruit were produced compared to the nontreated plots. Fewer 7 × 6 size fruit were produced in the first harvest with the two fumigants, but it was greater in the second and third harvests and for the season as a whole. There was no difference in the number of 6 × 6 size fruit in the first harvest, but fumigation increased production in the second and third harvests and for the season total. Generally, soil fumigation increased cull production, indicating that overall fruit production was greater with methyl bromide and 1,3-D compared to no treatment

or soil solarization. There was no difference in fruit production in any size category or marketable or cull yields between methyl bromide and 1,3-D + chloropicrin + pebulate. Yields of all sizes and grades were greatest with the fumigant treatments, intermediate with soil solarization and lowest where no soil treatment was applied.

In an attempt to explain some of the growth differences observed between fumigation and solarization, soil samples were obtained in early Nov. for analysis of elemental composition to determine if there were fewer nutrients left in the bed in nontreated and solarization plots, perhaps as a result of nutsedge growth. Few differences were observed (data not presented). Plots treated with 1,3-D + chloropicrin + pebulate had slightly more organic matter than the other treatments and the level of K was higher than observed in the nontreated plots. Sulfur also was present in greater quantity in the 1,3-D plots than in the nontreated or in the solarized plots, most likely reflecting the difference in organic matter. The lack of significant differences in elemental analysis between fumigation with methyl bromide and soil solarization suggests that soil nutrient concentrations were not a factor in the poor growth observed with soil solarization.

Double-cropped cucumber. Cucumber stands were higher with methyl bromide than with no fumigant (Table 5). Cu-

Table 4. Effect of fall applied methyl bromide alternatives on yield of fall tomato, 1998.

Treatment	Rate/acre	Number of 25 lb. cartons per acre				
		5 × 6	6 × 6	6 × 7	Marketable	Cull
-----First Harvest-----						
Nontreated	0	230 b	65 a	23 a	368 b	57 b
Methyl bromide	350 lb	663 a	54 a	4 b	721 a	103 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	606 a	61 a	4 b	667 a	134 a
Solarization + SoilGard	8 wk, drench	333 b	46 a	8 b	437 b	100 a
-----Second Harvest-----						
Nontreated	0	234 c	176 c	103 c	514 c	57 c
Methyl bromide	350 lb	970 a	621 a	330 a	1917 a	192 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	866 a	575 a	353 a	1794 a	218 a
Solarization + SoilGard	8 wk, drench	586 b	379 b	230 b	1196 b	123 b
-----Third Harvest-----						
Nontreated	0	31 b	65 c	80 c	176 c	46 c
Methyl bromide	350 lb	92 a	249 a	284 a ✓	625 a	165 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	73 a	207 ab	195 b ✓	471 ab	161 a
Solarization + SoilGard	8 wk, drench	61 ab	146 b	157 b	364 b	103 b
-----Season Total-----						
Nontreated	0	340 c	310 c	207 c	1058 c	161 c
Methyl bromide	350 lb	1729 a	920 a	621 a	3270 a ✓	460 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	1541 a	843 a	548 a	2932 a	514 a
Solarization + SoilGard	8 wk, drench	1031 b	572 b	395 b	1997 b ✓	326 b

*Mean separation by Duncan's new multiple range test, 5% level of significance.

Table 5. Effect of fall applied methyl bromide alternatives on early emergence (11 Mar.) and vigor (23 Apr.) of spring double-cropped cucumbers, weed control in the bed, rootknot nematode galling of cucumber roots, and yield of cucumbers. 1999.

Treatment	Rate/acre	No. of plants emerged/75 ft	Vigor (%)	Weed control (no of plants./70 ft of row)				Root galling Index	Yield (Bu./acre)
				Nutsedge	Crabgrass	Pigweed	Eclipta		
Nontreated	0	56 b ^a	71 b	576 a	14 ab	6 a	1 a	5.9 a	980 b
Methyl bromide	350 lb	62 a	82 a	116 b	6 b	1 a	1 a	1.7 b	1597 a
1,3-D + chloropicrin	35 gal	59 ab	78 ab	106 b	6 b	3 a	1 a	4.2 ab	1289 ab
Pebulate	4 lb								
Soil solarization + SoilGard (G. viridis)	8 wk drench	59 ab	68 b	52 b	24 a	4 a	2 a	6.3 a	826 b

Mean separation by Duncan's new multiple range test, 5% level of significance.

ucumber plant vigor was greater with methyl bromide than with soil solarization or no soil treatment but was not different from that observed with 1,3-D + chloropicrin + pebulate. Solarization did not improve vigor relative to the nontreated control.

Even though all of the nutsedge were desicated with atrachat after the final tomato harvest and again shortly before seeding cucumbers, by Apr., nutsedge was once again present in all plots but with no difference in numbers emerged through the plastic with either fumigant treatment or with solarization (Table 5). Interestingly, the number of nutsedge plants had increased in methyl bromide treated plots compared to what was observed during the fall tomato crop, indicating that the nutsedge population already was beginning to rebound and demonstrating that even with methyl bromide, it is not a case of nutsedge eradication but rather nutsedge management. Significantly more crabgrass was present in the beds of solarization plots than in fumigated plots, but there were no differences in populations of pigweed or eclipta [*Eclipta alba* (L.) Hassk.].

The extent of root galling by rootknot nematodes was assessed visually after the last harvest (Table 5). There was considerable galling on the cucumber roots in this experiment and there was some variation in the extent among replications as well as treatments. Methyl bromide was the only treatment to significantly reduce gall formation relative to the nontreated control treatment. The degree of galling with soil solarization was the same as that with no fumigant, whereas 1,3-D was intermediate between methyl bromide and solarization, i.e., not significantly different from either.

Cucumbers were harvested 8 times during the spring season. Fruit yields with methyl bromide applied the previous fall were greater than with solarization or no soil treatment (Table 5). Cucumber production in solarized plots was equal to the nontreated. Production of slicer cucumbers in soil treated

in the fall with 1,3-D + chloropicrin + pebulate was not significantly different from that observed with methyl bromide or solarization, indicating that the 1,3-D treatment was intermediate. The average weight of an individual cucumber was not affected by treatment (data not presented).

Millet cover crop. Fall soil treatment affected the growth of millet as a cover crop the following spring and the growth of weeds (Table 6). Millet canopy coverage was reduced where no fumigant was applied or soil solarization was practiced. Millet was taller in soil fumigated with methyl bromide or 1,3-D + chloropicrin with pebulate herbicide than in the nontreated soil. Methyl bromide also produced taller millet than was observed in solarized plots, whereas 1,3-D was intermediate between the two treatments. There was no difference in fresh weight of millet among the treatments; however, crabgrass was difficult to separate from millet once cut and some of the weight recorded in solarized and nontreated plots may have been due to crabgrass and not millet. Nutsedge population was not affected by fall treatment nor was pigweed, but there was significantly less crabgrass in plots which were treated with fumigant in the fall as compared to solarization or nontreatment, suggesting that this reduction was the result of the improved growth of millet in the fumigant plots as indicated by millet canopy estimates.

Results of these studies indicate that 1,3-D + chloropicrin + pebulate can provide broadspectrum pest control in fall tomato comparable to that obtained with methyl bromide. Purple nutsedge control can be challenging, but the addition of pebulate overcomes the short comings of 1,3-D + chloropicrin, as has been demonstrated in previous research (Gilreath et al., 1994). Resurgence of rootknot nematodes was a problem with all treatments, but it was especially troublesome with solarization. Fumigation with 1,3-D + chloropicrin controlled rootknot nematodes for the tomato crop, but the extent of root galling increased during the cucumber crop. Soil solar-

Table 6. Effect of fall applied methyl bromide alternatives on growth of a brown top millet cover crop and weeds in the millet in the following spring.

Treatment	Rate/acre	Millet				Control (%)	
		Canopy (%)	Height (inches)	Fresh wt (tons/acre)	Nutsedge no./5.5 ft ²	Crabgrass	Pigweed
Nontreated	0	28 b ^a	21 c	6.8 a	6 a	58 a	10 a
Methyl bromide	350 lb	76 a	32 a	6.9 a	0 a	18 b	6 a
1,3-D + chloropicrin + pebulate	35 gal + 4 lb	61 a	30 ab	7.7 a	7 a	21 b	11 a
Soil solarization + SoilGard (G. viridis)	8 wk, drench	32 b	25 bc	7.1 a	1 a	69 a	8 a

Mean separation by Duncan's new multiple range test, 5% level of significance.

tion did not perform well in this study for either the fall tomato crop or the spring double cropped cucumbers. Considerable variation in results existed among replications for treatments, but this was especially true with solarization. This serves to point out the highly variable nature of solarization as an alternative to methyl bromide and the need for more research to elucidate those variables which are responsible for this erratic performance and to identify ways of enhancing performance of soil solarization under Florida conditions. Performance of spring cover crops, such as millet, so may be affected by the soilborne pest control program employed the previous fall, as evidenced by the growth performance of millet in this study. Not only did the fall fumigation program impact millet growth, but indirectly through the effect of millet growth on weed emergence and growth, it produced a noticeable effect on weed control in the spring millet crop. The interrelationship of soilborne pests and cropping and soil fumigation practices is a complex one. It is becoming apparent that any one practice can produce effects which span beyond the present crop into near term future crops. The loss of methyl bromide will serve to expand our knowledge of these relationships.

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For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: chloropicrin

[Insert Alternative]

Study: Strawberry production with alternatives to methyl bromide

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

This alternative can be used in tomato, strawberry, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Locascio, Olson, Chase, Sinclair, Dickson, Mitchell and Chellemi

3. Publication and Date of Publication Proc. of 1999 Annual International Research Conf. on Methyl Bromide Alternatives, 1999

4. Location of research study Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

6. Was crop yield measured in the study? Yes X No _____

7. Describe the effectiveness of the alternative in controlling pests in the study.

Similar results (not effective) would be expected in North Carolina in control of yellow nutsedge by this alternative. Effectiveness was not acceptable for control.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Similar results would be expected in North Carolina across strawberry, tomato, cucurbit crops and pepper.

Research Summary Table

Alternative: ChloropicrinStudy: Locascio et al., 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (no. per m ²) (penetrating plastic)						Pest 2: Nutsedge (no. per m ²) (under plastic)						Yield (flats/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	untreated		6 wks	22					6 wks	16					1,705
2	methyl bromide +														
	chloropicrin	347 lbs./acre	6 wks	0					6 wks	0.9					4,131
3	chloropicrin	303 lbs./acre	6 wks	5					6 wks	1.3					3,311

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

03-0041

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
chloropicrin	nutsedge	chloropicrin		303	22	gal	\$ 2.50	\$ 75.00	80	100	1	\$ 912.50
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 912.50

Comments:

03-0041

Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Strawberry	grade, time, market	flats	1,340.00	\$ 8.00	\$ 10,720.00
				Total Revenue	\$ 10,720.00

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

03-0040

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No change

1999

Annual
International Research
Conference
On
Methyl Bromide
Alternatives
And Emissions Reductions

November 1 – 4, 1999

The DoubleTree Hotel
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Sponsored by
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U S Environmental Protection Agency
And
U S Department of Agriculture

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Support Provided by the UNEP TIE

STRAWBERRY PRODUCTION WITH ALTERNATIVES TO METHYL BROMIDE FUMIGATION

S.J. Locascio^{1,3*}, S.M. Olson^{1,4}, C.A. Chase^{2,3}, T. R. Sinclair^{2,3}, D.W. Dickson^{1,3}, D. J. Mitchell^{1,3}, and D. O. Chellemi^{2,5} University of Florida¹, and USDA-ARS², Gainesville, FL 32611-0690³, Quincy, FL 32351-9500⁴, and Fort Pierce, FL 34945-3138⁵

Strawberries were transplanted in the fall of 1997 to polyethylene mulched beds in Gainesville on a Millhopper fine sand and in Quincy on an Orangeburg fine sandy loam to evaluate the effects of soil fumigants and solarization on fruit production and reported (Locascio, et al., 1999). Fumigant and solarization treatments were applied on Aug. 21 and 19, 1997, respectively. On selected plots, napropamide was applied at 4.8 kg/ha for weed control and fumigant metam-Na at 300 L/ha were rototilled into the bed. Soil fumigants were injected with two chisels per bed spaced 30 cm apart at a depth of 20 to 25 cm at 390 kg/ha 67 % MBr + 33 % Pic, 340 kg/ha Pic, 327 L/ha a C-17, and C-35, and 440 kg/ha dazomet. Drip tubing was placed on the beds before application of 38.1 μ m (1.5 mil) black polyethylene mulch or 102 μ m (4 mil) clear thermal infrared-absorbing film (AT Plastics, Inc., Edmonton, Canada). Soil temperature was measured at 0- to 25-cm depths in two plots mulched with black and in four plots mulched with the clear film (Chase et al., 1997). Some clear mulches (Table 1) were painted with black latex paint a week before transplanting. 'Chandler' was transplants on Oct.21 and Nov.7, respectively.

Transplants were sampled for fungal colonization of roots on 24 Oct. Fruits were harvested twice weekly, graded and weighed. Soil and plants were sampled for nematode and fungal populations at Gainesville at the end of the harvest season on May 18.

Fungi were isolated from the roots and crown tissue of every plant sampled before transplanting. VA mycorrhizal fungi were observed on 95% of the root samples. *Alternaria*, *Fusarium*, *Rhizoctonia*, *Trichoderma*, and an unknown pycnidial forming fungus were isolated from 5, 35, 25, 5, and 5% of the crown pieces, respectively. Although some species of *Alternaria*, *Fusarium*, and *Rhizoctonia* may cause root diseases, it was not possible to determine the source of pathogens isolated from roots during the growing season and at harvest.

Solar radiation and soil temperatures decreased over the measurement periods (60 days) from Aug. to Oct. Soil temperatures by late Sept. were insufficient to control nutsedge tubers or to kill emerged shoots trapped under the clear film. Maximum soil temperatures exceeding 45 C with the clear mulch at 10 cm occurred on less than 2 % of the days. By the sixth week of solarization at Gainesville, nutsedge density in the control treatment was 22 plants m⁻² (Table 1). Metam-Na + napropamide was the only treatment that failed to reduce the number of nutsedge plants penetrating the mulches. All other treatments significantly reduced nutsedge densities to levels that were statistically similar to that

with MBr-Pic. By Dec., it was apparent that painting the solarization film before transplanting was necessary. The clear film maintained soil temperatures that were sufficiently warm to promote the sprouting of tubers but not hot enough to cause foliar scorching of the shoots trapped under the film. The cooler temperatures apparently induced nutsedge dormancy since the nutsedge pressure was relatively low with all other treatments. By the end of the crop, nutsedge densities under the solarization films were greater than with the black films (Table 1).

At Gainesville, strawberry plant growth was slow, possibly due to the high occurrence of rainfall after transplanting. Rainfall exceeded average in each month from transplanting through Mar. Rainfall in Feb. was approximately three times the average. Plant vigor ratings were made on Jan. 29, 1998 (Table 1). Plant growth rating of plants with no treatment was only 2.5 on a rating of 1 (poor growth) to 10 (excellent growth) and was significantly greater with all treatments except that with the unpainted clear mulch solarization treatment. Marketable fruit yields were significantly higher with MBr-Pic than with no fumigant, metam-Na with and without Pic, and with the soil solarization treatment-mulch painted black before transplanting (Table 1). Total fruit yields in flats/ha were highest with MBr-Pic (4,131), C-17 (3,620), C-35 (3,541), Pic (3,311), and soil solarization with metam-Na-mulch painted (3,002), and significantly lower with metam-Na (2,552), soil solarization-mulch painted (2,710), metam-Na + Pic (2,199) and the check (1,705). Fruit was not obtained with soil solarization-clear mulch not painted. Weed growth under the clear mulch was extensive and picked the mulch up 7.5 to 15 cm over the soil; thus, strawberry plants did not survive the weed competition.

At Quincy, strawberry plant growth was excellent and fruit yields are shown in Table 2. Total fruit yield (in flats/ha) was highest with Pic (4,040), MBr-Pic (3,511), C-35 (3,553), C-17 (3,333), Metam-Na + Pic (3,279), Dazomet (3,620), and Dazomet + solarization-mulch painted (3,543). Lower yields were obtained with solarization-mulch painted (3,210) and with metam-Na + Pic (3,116) and with no fumigant (2,417). The lowest yield was obtained with solarization-mulch not painted (815). Fruit size response to fumigant treatment was similar to that obtained for total yield. Marketable fruit were larger with treatments that resulted in higher yield and smaller with treatments that resulted in lower yields. Nutsedge counts were made on Sept. 30 and data are shown in Table 2. Nutsedge control was excellent with MBr-Pic, and with all solarization treatments, intermediate with C-17 and C-35 + napropamide, and poorest with Pic, metam-Na-Pic and dazomet each + napropamide and with the untreated check.

Roots and crowns of strawberry plants in all soil treatments at the end of the season were colonized by a wide array and diversity of fungi, and high incidences of colonization were attained by many of them. Fungi in 18 genera were isolated from roots. Incidences of infection of plants by potentially damaging pathogenic fungi included 29-59% with *Alternaria* spp., 13-42% with *Sclerotium rolfsii*, 50-83% with *Colletotrichum* spp., 13-59% with *Curvularia* spp., 75-96% with *Fusarium oxysporum*, 4-17% with *Macrophomina phaseolina*, 29-79% with *Phoma* spp., 17-42% with *Pythium aphanidermatum*, 4-17% with other *Pythium* spp., and 67-92% with *Rhizoctonia solani*.

Table 1. Effect of fumigant treatments on fruit yield, plant vigor, and nutsedge counts of 'Chandler' strawberries. Gainesville, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Plant vigor ^y (Jan 29)	Nutsedge (plants/m ²)		
				Through film film Oct 8 May 18	Under May 18	
1 Untreated		1705 d ^w	2.5 d	21.5 a	8.5	16.1 bc
2 Methyl bromide /Pic (67/33)	390 kg	4131 a	10.0 a	0.0 b	0.0	0.9 c
3 Chloropicrin (Pic) ^z	340 kg	3311 abc	6.8 bc	5.0 b	4.5	1.3 c
4 1,3-D + 35 % Pic ^z	327 L	3541 ab	8.0 b	3.4 b	0.9	4.0 c
5 1,3-D + 17 % Pic ^z	327 L	3620 ab	6.8 bc	0.8 b	20.2	16.6 bc
6 Metam-Na ^z	300 L	2552 bcd	5.5 c	28.4 b	12.1	13.9 bc
7 Metam-Na + Pic ^z	300 L + 170 kg	2199 cd	4.8 c	5.0 b	1.3	6.3 c
8 Solarization ^x		---	1.0 d	0.0 b	0.0	45.7 ab
9 Solarization ^y		2710 bcd	5.5 c	0.4 b	0.0	49.3 a
10 Metam-Na + Pic + solarization ^y	300 L + 170 kg	3002 abcd	6.0 bc	0.0 b	0.5	44.8 ab

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear and due to excessive weed growth, fruit was not harvested.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^y Plant vigor ratings with 10 = maximum growth and 1 = 10 % of maximum growth.

In general, the high incidence of pathogenic fungi, especially *S. rolfsii*, *F. oxysporum*, *P. aphanidermatum*, and *R. solani*, and the severity of root disease caused by them undoubtedly contributed to poor plant growth, early plant mortality, and low yields at Gainesville. Fumigation probably delay the time of infection by fungi dispersed into treated soil and allowed increased yields before pathogenic fungi reach high levels of colonization and cause severe disease.

The population densities of the highly pathogenic sting (*Belonolaimus longicaudatus*) nematode at the end of the season at Gainesville was low and not affected by treatment (data not shown).

In summary, early plant growth and yields at Gainesville were poorer than expected, probably due the high incidences of fungal root diseases and to excessive rainfall during Dec. to Mar. The yield with MBr-Pic was statistically similar to that with 1,3-dichloropropene + 17% Pic (C-17), C-35, Pic, and soil solarization + metam-Na-mulch painted black before transplanting. Yields were significantly lower with the check, metam Na, metam Na + Pic, and soil solarization-mulch painted before planting than with MBr-Pic. At Quincy, plant growth was excellent and yields were statistically similar with Pic, MBr-Pic (67:33), dazomet, solarization + dazomet-mulch painted black, C-17, C35, and metam-Na + Pic. Lowest yields were obtained with the untreated check and solarization-mulch not painted black before planting. Soil solarization with the mulch painted black suppressed nutsedge but regrowth occurred with the mulch left clear. At Gainesville, treatment had no effect on sting nematode (*Belonolaimus longicaudatus*) population densities extracted from soil samples or fungi populations on plant roots at the end of the season.

Literature Cited

Chase, C.A., T. R. Sinclair, S.J. Locascio, J.P. Gilreath, J.P. Jones, and D.W. Dickson. 1997. An evaluation of improved polyethylene films for cool-season soil solarization. Proc. Fla. State Hort. Soc. 110:326-329.

Locascio, S. J., S. M. Olson, C. A. Chase, T. R. Sinclair, D. W. Dickson, D. J. Mitchell, and D. O. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Proc. National Agric. Plastics Congress. 28:148-154.

03-0041

3-A(1)h

For EPA Use Only
ID#**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: solarization

[Insert Alternative]

Study: Strawberry production with alternatives to methyl bromide

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted _____

1b. Township caps _____

1c. Alternative not acceptable in consuming country _____

1d. Other (Please describe) _____

X

This alternative can be used in tomato, strawberry, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide****Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website?

Yes _____

No _____

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Locascio, Olson, Chase, Sinclair, Dickson, Mitchell
and Chellemi

3. Publication and Date of Publication

Proc. of 1999 Annual International Research Conf. on
Methyl Bromide Alternatives, 1999

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

Solarization

6. Was crop yield measured in the study?

Yes

X

No _____

7. Describe the effectiveness of the alternative in controlling pests in the study.

Similar results (not effective) would be expected in North Carolina in control
of yellow nutsedge by this alternative. Effectiveness was not acceptable
for control.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Similar results would be expected in North Carolina across strawberry, tomato,
cucurbit crops and pepper.

Research Summary Table

Alternative: SolarizationStudy: Locascio et al., 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number List the treatment number from the research study you are citing.

Col. B: Treatment List what type of pest control method was used.

Col. C: Rate Enter the pounds or gallons of a chemical used, days of solarization, etc.

Col. D, F, H, J, L, N: Interval Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).

Cols. E, G, I, K, M, O: Rating for Interval: Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.

Control of Pests 1 and 2 (Cols. D - I and Cols. J - O): For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).

Col. J: Yield Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (no. per m ²) (under plastic)						Pest 2						Yield (flats/acre)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	untreated		6 WAT	16											690
2	methyl bromide +														
	chloropicrin	347	6 WAT	0.9											1,672.5
3	solarization		6 WAT	46											0

Comments:

Solarization

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

[illegible]

Comments:

1400-0041-03

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

ID#

Solarization

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item.	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No change

03-0041

1999

Annual
International Research
Conference
On
Methyl Bromide
Alternatives
And Emissions Reductions

November 1 - 4, 1999

The DoubleTree Hotel
Mission Valley
7450 Hazard Center Drive
San Diego, California 92108

Sponsored by
Methyl Bromide Alternatives Outreach

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Crop Protection Coalition
U S Environmental Protection Agency
And
U S Department of Agriculture

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STRAWBERRY PRODUCTION WITH ALTERNATIVES TO METHYL BROMIDE FUMIGATION

S.J. Locascio^{1,3*}, S.M. Olson^{1,4}, C.A. Chase^{2,3}, T. R. Sinclair^{2,3}, D.W. Dickson^{1,3}, D. J. Mitchell^{1,3}, and D. O. Chellemi^{2,5} University of Florida¹, and USDA-ARS², Gainesville, FL 32611-0690³, Quincy, FL 32351-9500⁴, and Fort Pierce, FL 34945-3138⁵

Strawberries were transplanted in the fall of 1997 to polyethylene mulched beds in Gainesville on a Millhopper fine sand and in Quincy on an Orangeburg fine sandy loam to evaluate the effects of soil fumigants and solarization on fruit production and reported (Locascio, et al., 1999). Fumigant and solarization treatments were applied on Aug. 21 and 19, 1997, respectively. On selected plots, napropamide was applied at 4.8 kg/ha for weed control and fumigant metam-Na at 300 L/ha were rototilled into the bed. Soil fumigants were injected with two chisels per bed spaced 30 cm apart at a depth of 20 to 25 cm at 390 kg/ha 67 % MBr + 33 % Pic, 340 kg/ha Pic, 327 L/ha a C-17, and C-35, and 440 kg/ha dazomet. Drip tubing was placed on the beds before application of 38.1 μ m (1.5 mil) black polyethylene mulch or 102 μ m (4 mil) clear thermal infrared-absorbing film (AT Plastics, Inc., Edmonton, Canada). Soil temperature was measured at 0- to 25-cm depths in two plots mulched with black and in four plots mulched with the clear film (Chase et al., 1997). Some clear mulches (Table 1) were painted with black latex paint a week before transplanting. 'Chandler' was transplants on Oct.21 and Nov.7, respectively.

Transplants were sampled for fungal colonization of roots on 24 Oct. Fruits were harvested twice weekly, graded and weighed. Soil and plants were sampled for nematode and fungal populations at Gainesville at the end of the harvest season on May 18.

Fungi were isolated from the roots and crown tissue of every plant sampled before transplanting. VA mycorrhizal fungi were observed on 95% of the root samples. *Alternaria*, *Fusarium*, *Rhizoctonia*, *Trichoderma*, and an unknown pycnidial forming fungus were isolated from 5, 35, 25, 5, and 5% of the crown pieces, respectively. Although some species of *Alternaria*, *Fusarium*, and *Rhizoctonia* may cause root diseases, it was not possible to determine the source of pathogens isolated from roots during the growing season and at harvest.

Solar radiation and soil temperatures decreased over the measurement periods (60 days) from Aug. to Oct. Soil temperatures by late Sept. were insufficient to control nutsedge tubers or to kill emerged shoots trapped under the clear film. Maximum soil temperatures exceeding 45 C with the clear mulch at 10 cm occurred on less than 2 % of the days. By the sixth week of solarization at Gainesville, nutsedge density in the control treatment was 22 plants m⁻² (Table 1). Metam-Na + napropamide was the only treatment that failed to reduce the number of nutsedge plants penetrating the mulches. All other treatments significantly reduced nutsedge densities to levels that were statistically similar to that

with MBr-Pic. By Dec., it was apparent that painting the solarization film before transplanting was necessary. The clear film maintained soil temperatures that were sufficiently warm to promote the sprouting of tubers but not hot enough to cause foliar scorching of the shoots trapped under the film. The cooler temperatures apparently induced nutsedge dormancy since the nutsedge pressure was relatively low with all other treatments. By the end of the crop, nutsedge densities under the solarization films were greater than with the black films (Table 1).

At Gainesville, strawberry plant growth was slow, possibly due to the high occurrence of rainfall after transplanting. Rainfall exceeded average in each month from transplanting through Mar. Rainfall in Feb. was approximately three times the average. Plant vigor ratings were made on Jan. 29, 1998 (Table 1). Plant growth rating of plants with no treatment was only 2.5 on a rating of 1 (poor growth) to 10 (excellent growth) and was significantly greater with all treatments except that with the unpainted clear mulch solarization treatment. Marketable fruit yields were significantly higher with MBr-Pic than with no fumigant, metam-Na with and without Pic, and with the soil solarization treatment-mulch painted black before transplanting (Table 1). Total fruit yields in flats/ha were highest with MBr-Pic (4,131), C-17 (3,620), C-35 (3,541), Pic (3,311), and soil solarization with metam-Na-mulch painted (3,002), and significantly lower with metam-Na (2,552), soil solarization-mulch painted (2,710), metam-Na + Pic (2,199) and the check (1,705). Fruit was not obtained with soil solarization-clear mulch not painted. Weed growth under the clear mulch was extensive and picked the mulch up 7.5 to 15 cm over the soil; thus, strawberry plants did not survive the weed competition.

At Quincy, strawberry plant growth was excellent and fruit yields are shown in Table 2. Total fruit yield (in flats/ha) was highest with Pic (4,040), MBr-Pic (3,511), C-35 (3,553), C-17 (3,333), Metam-Na + Pic (3,279), Dazomet (3,620), and Dazomet + solarization-mulch painted (3,543). Lower yields were obtained with solarization-mulch painted (3,210) and with metam-Na + Pic (3,116) and with no fumigant (2,417). The lowest yield was obtained with solarization-mulch not painted (815). Fruit size response to fumigant treatment was similar to that obtained for total yield. Marketable fruit were larger with treatments that resulted in higher yield and smaller with treatments that resulted in lower yields. Nutsedge counts were made on Sept. 30 and data are shown in Table 2. Nutsedge control was excellent with MBr-Pic, and with all solarization treatments, intermediate with C-17 and C-35 + napropamide, and poorest with Pic, metam-Na-Pic and dazomet each + napropamide and with the untreated check.

Roots and crowns of strawberry plants in all soil treatments at the end of the season were colonized by a wide array and diversity of fungi, and high incidences of colonization were attained by many of them. Fungi in 18 genera were isolated from roots. Incidences of infection of plants by potentially damaging pathogenic fungi included 29-59% with *Alternaria* spp., 13-42% with *Sclerotium rolfsii*, 50-83% with *Colletotrichum* spp., 13-59% with *Curvularia* spp., 75-96% with *Fusarium oxysporum*, 4-17% with *Macrophomina phaseolina*, 29-79% with *Phoma* spp., 17-42% with *Pythium aphanidermatum*, 4-17% with other *Pythium* spp., and 67-92% with *Rhizoctonia solani*.

Table 1. Effect of fumigant treatments on fruit yield, plant vigor, and nutsedge counts of 'Chandler' strawberries. Gainesville, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Plant vigor ^y (Jan 29)	Nutsedge (plants/m ²)		
				Through film film Oct 8 May 18	Under May 18	
1 Untreated		1705 d ^w	2.5 d	21.5 a	8.5	16.1 bc
2 Methyl bromide /Pic (67/33)	390 kg	4131 a	10.0 a	0.0 b	0.0	0.9 c
3 Chloropicrin (Pic) ^z	340 kg	3311 abc	6.8 bc	5.0 b	4.5	1.3 c
4 1,3-D + 35 % Pic ^z	327 L	3541 ab	8.0 b	3.4 b	0.9	4.0 c
5 1,3-D + 17 % Pic ^z	327 L	3620 ab	6.8 bc	0.8 b	20.2	16.6 bc
6 Metam-Na ^z	300 L	2552 bcd	5.5 c	28.4 b	12.1	13.9 bc
7 Metam-Na + Pic ^z	300 L + 170 kg	2199 cd	4.8 c	5.0 b	1.3	6.3 c
8 Solarization ^x		---	1.0 d	0.0 b	0.0	45.7 ab
9 Solarization ^y		2710 bcd	5.5 c	0.4 b	0.0	49.3 a
10 Metam-Na + Pic + solarization ^y	300 L + 170 kg	3002 abcd	6.0 bc	0.0 b	0.5	44.8 ab

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear and due to excessive weed growth, fruit was not harvested.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^v Plant vigor ratings with 10 = maximum growth and 1 = 10 % of maximum growth.

Table 2. Effect of fumigant treatments on yield, fruit weight, and nutsedge counts of 'Chandler' strawberries. NFREC, Quincy, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Size (g/fruit)	Nutsedge (plants/m ²) ^y
Untreated		2417 c ^w	15.5 c	29.3 ab
Methyl bromide /Pic (67/33)	390 kg	3511 ab	17.0 ab	1.0 d
Chloropicrin (Pic) ^z	340 kg	4040 a	17.4 ab	20.2 abc
1,3-D + 35 % Pic ^z	327 L	3553 ab	17.1 ab	10.1 cd
1,3-D + 17 % Pic ^z	327 L	3333 ab	17.2 ab	13.2 bcd
Metam-Na + Pic ^z	300 L + 170 kg	3279 ab	16.9 abc	19.8 abc
Metam-Na ^z	300 L	2933 bc	16.1 bc	30.4 a
Dazomet ^z	440 kg	3620 ab	17.1 ab	33.7 a
Solarization ^x		815 d	13.4 d	0.1 d
Solarization ^y		3210 b	16.2 abc	0.2 d
Metam-Na + Pic + solarization ^y	300 L + 170 kg	3116 bc	16.1 bc	0.1 d
Dazomet +solarization ^y	440 kg	3543 ab	17.7 a	0.1 d

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^v Nutsedge shoots penetrating mulch counted on Sept. 30.

In general, the high incidence of pathogenic fungi, especially *S. rolfsii*, *F. oxysporum*, *P. aphanidermatum*, and *R. solani*, and the severity of root disease caused by them undoubtedly contributed to poor plant growth, early plant mortality, and low yields at Gainesville. Fumigation probably delay the time of infection by fungi dispersed into treated soil and allowed increased yields before pathogenic fungi reach high levels of colonization and cause severe disease.

The population densities of the highly pathogenic sting (*Belonolaimus longicaudatus*) nematode at the end of the season at Gainesville was low and not affected by treatment (data not shown).

In summary, early plant growth and yields at Gainesville were poorer than expected, probably due the high incidences of fungal root diseases and to excessive rainfall during Dec. to Mar. The yield with MBr-Pic was statistically similar to that with 1,3-dichloropropene + 17% Pic (C-17), C-35, Pic, and soil solarization + metam-Na-mulch painted black before transplanting. Yields were significantly lower with the check, metam Na, metam Na + Pic, and soil solarization-mulch painted before planting than with MBr-Pic. At Quincy, plant growth was excellent and yields were statistically similar with Pic, MBr-Pic (67:33), dazomet, solarization + dazomet-mulch painted black, C-17, C35, and metam-Na + Pic. Lowest yields were obtained with the untreated check and solarization-mulch not painted black before planting. Soil solarization with the mulch painted black suppressed nutsedge but regrowth occurred with the mulch left clear. At Gainesville, treatment had no effect on sting nematode (*Belonolaimus longicaudatus*) population densities extracted from soil samples or fungi populations on plant roots at the end of the season.

Literature Cited

Chase, C.A., T. R. Sinclair, S.J. Locascio, J.P. Gilreath, J.P. Jones, and D.W. Dickson. 1997. An evaluation of improved polyethylene films for cool-season soil solarization. Proc. Fla. State Hort. Soc. 110:326-329.

Locascio, S. J., S. M. Olson, C. A. Chase, T. R. Sinclair, D. W. Dickson, D. J. Mitchell, and D. O. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Proc. National Agric. Plastics Congress. 28:148-154.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + chloropicrin

[Insert Alternative]

Study: Strawberry production with alternatives to methyl bromide

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

This alternative can be used in tomato, strawberry, pepper and
cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only

ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website? Yes _____ No _____

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Locascio, Olson, Chase, Sinclair, Dickson, Mitchell
and Chellemi3. Publication and Date of Publication Proc. of 1999 Annual International Research Conf. on
Methyl Bromide Alternatives, 19994. Location of research study Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

1,3-D + chloropicrin6. Was crop yield measured in the study? Yes X No _____

7. Describe the effectiveness of the alternative in controlling pests in the study.

Similar results (not effective) would be expected in North Carolina in control
of yellow nutsedge by this alternative. Effectiveness was not acceptable
for control.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Similar results would be expected in North Carolina across strawberry, tomato,
cucurbit crops and pepper.

Research Summary Table

Alternative: 1,3-D + ChloropicrinStudy: Locascio et al., 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. ai per area)	Pest 1: Nutsedge (no. per m ²) (penetrating plastic)						Pest 2: Nutsedge (no. per m ²) (under plastic)						Yield (flats/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	untreated		8 wks	22					8 wks	16					1,705
2	methyl bromide +														
	chloropicrin	347 lbs./acre	6 wks	0					6 wks	0.9					4,131
4	1,3-D +														
	chloropicrin	35 gal/acre	6 wks	3.4					6 wks	4					3,541

Comments:

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
1,3-D +	nutsedge	1,3-D	65	239.4						100	1	\$ 458.50
chloropicrin		chloropicrin	35	136.2	.35	gal	\$ 13.10	\$ 75.00	80			
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 458.50

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

If a consortium is submitting this application, the data for this table should reflect a representative user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle.

If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.

Col. C: Unit of Crop/Commodity

Enter the unit of measurement for your crop/commodity.

Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.

Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.

Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F

[illegible]

Comments:

Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

1,3-D + Chloropicrin

#Q1

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Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:**1,3-D + Chloropicrin**

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item.	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No change

03-0041

1999

Annual
International Research
Conference
On
Methyl Bromide
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And Emissions Reductions

November 1 – 4, 1999

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STRAWBERRY PRODUCTION WITH ALTERNATIVES TO METHYL BROMIDE FUMIGATION

S.J. Locascio^{1,3*}, S.M. Olson^{1,4}, C.A. Chase^{2,3}, T. R. Sinclair^{2,3}, D.W. Dickson^{1,3}, D. J. Mitchell^{1,3}, and D. O. Chellemi^{2,5} University of Florida¹, and USDA-ARS², Gainesville, FL 32611-0690³, Quincy, FL 32351-9500⁴, and Fort Pierce, FL 34945-3138⁵

Strawberries were transplanted in the fall of 1997 to polyethylene mulched beds in Gainesville on a Millhopper fine sand and in Quincy on an Orangeburg fine sandy loam to evaluate the effects of soil fumigants and solarization on fruit production and reported (Locascio, et al., 1999). Fumigant and solarization treatments were applied on Aug. 21 and 19, 1997, respectively. On selected plots, napropamide was applied at 4.8 kg/ha for weed control and fumigant metam-Na at 300 L/ha were rototilled into the bed. Soil fumigants were injected with two chisels per bed spaced 30 cm apart at a depth of 20 to 25 cm at 390 kg/ha 67 % MBr + 33 % Pic, 340 kg/ha Pic, 327 L/ha a C-17, and C-35, and 440 kg/ha dazomet. Drip tubing was placed on the beds before application of 38.1 μ m (1.5 mil) black polyethylene mulch or 102 μ m (4 mil) clear thermal infrared-absorbing film (AT Plastics, Inc., Edmonton, Canada). Soil temperature was measured at 0- to 25-cm depths in two plots mulched with black and in four plots mulched with the clear film (Chase et al., 1997). Some clear mulches (Table 1) were painted with black latex paint a week before transplanting. 'Chandler' was transplants on Oct.21 and Nov.7, respectively.

Transplants were sampled for fungal colonization of roots on 24 Oct. Fruits were harvested twice weekly, graded and weighed. Soil and plants were sampled for nematode and fungal populations at Gainesville at the end of the harvest season on May 18.

Fungi were isolated from the roots and crown tissue of every plant sampled before transplanting. VA mycorrhizal fungi were observed on 95% of the root samples. *Alternaria*, *Fusarium*, *Rhizoctonia*, *Trichoderma*, and an unknown pycnidial forming fungus were isolated from 5, 35, 25, 5, and 5% of the crown pieces, respectively. Although some species of *Alternaria*, *Fusarium*, and *Rhizoctonia* may cause root diseases, it was not possible to determine the source of pathogens isolated from roots during the growing season and at harvest.

Solar radiation and soil temperatures decreased over the measurement periods (60 days) from Aug. to Oct. Soil temperatures by late Sept. were insufficient to control nutsedge tubers or to kill emerged shoots trapped under the clear film. Maximum soil temperatures exceeding 45 C with the clear mulch at 10 cm occurred on less than 2 % of the days. By the sixth week of solarization at Gainesville, nutsedge density in the control treatment was 22 plants m⁻² (Table 1). Metam-Na + napropamide was the only treatment that failed to reduce the number of nutsedge plants penetrating the mulches. All other treatments significantly reduced nutsedge densities to levels that were statistically similar to that

with MBr-Pic. By Dec., it was apparent that painting the solarization film before transplanting was necessary. The clear film maintained soil temperatures that were sufficiently warm to promote the sprouting of tubers but not hot enough to cause foliar scorching of the shoots trapped under the film. The cooler temperatures apparently induced nutsedge dormancy since the nutsedge pressure was relatively low with all other treatments. By the end of the crop, nutsedge densities under the solarization films were greater than with the black films (Table 1).

At Gainesville, strawberry plant growth was slow, possibly due to the high occurrence of rainfall after transplanting. Rainfall exceeded average in each month from transplanting through Mar. Rainfall in Feb. was approximately three times the average. Plant vigor ratings were made on Jan. 29, 1998 (Table 1). Plant growth rating of plants with no treatment was only 2.5 on a rating of 1 (poor growth) to 10 (excellent growth) and was significantly greater with all treatments except that with the unpainted clear mulch solarization treatment. Marketable fruit yields were significantly higher with MBr-Pic than with no fumigant, metam-Na with and without Pic, and with the soil solarization treatment-mulch painted black before transplanting (Table 1). Total fruit yields in flats/ha were highest with MBr-Pic (4,131), C-17 (3,620), C-35 (3,541), Pic (3,311), and soil solarization with metam-Na-mulch painted (3,002), and significantly lower with metam-Na (2,552), soil solarization-mulch painted (2,710), metam-Na + Pic (2,199) and the check (1,705). Fruit was not obtained with soil solarization-clear mulch not painted. Weed growth under the clear mulch was extensive and picked the mulch up 7.5 to 15 cm over the soil; thus, strawberry plants did not survive the weed competition.

At Quincy, strawberry plant growth was excellent and fruit yields are shown in Table 2. Total fruit yield (in flats/ha) was highest with Pic (4,040), MBr-Pic (3,511), C-35 (3,553), C-17 (3,333), Metam-Na + Pic (3,279), Dazomet (3,620), and Dazomet + solarization-mulch painted (3,543). Lower yields were obtained with solarization-mulch painted (3,210) and with metam-Na + Pic (3,116) and with no fumigant (2,417). The lowest yield was obtained with solarization-mulch not painted (815). Fruit size response to fumigant treatment was similar to that obtained for total yield. Marketable fruit were larger with treatments that resulted in higher yield and smaller with treatments that resulted in lower yields. Nutsedge counts were made on Sept. 30 and data are shown in Table 2. Nutsedge control was excellent with MBr-Pic, and with all solarization treatments, intermediate with C-17 and C-35 + napropamide, and poorest with Pic, metam-Na-Pic and dazomet each + napropamide and with the untreated check.

Roots and crowns of strawberry plants in all soil treatments at the end of the season were colonized by a wide array and diversity of fungi, and high incidences of colonization were attained by many of them. Fungi in 18 genera were isolated from roots. Incidences of infection of plants by potentially damaging pathogenic fungi included 29-59% with *Alternaria* spp., 13-42% with *Sclerotium rolfsii*, 50-83% with *Colletotrichum* spp., 13-59% with *Curvularia* spp., 75-96% with *Fusarium oxysporum*, 4-17% with *Macrophomina phaseolina*, 29-79% with *Phoma* spp., 17-42% with *Pythium aphanidermatum*, 4-17% with other *Pythium* spp., and 67-92% with *Rhizoctonia solani*.

Table 1. Effect of fumigant treatments on fruit yield, plant vigor, and nutsedge counts of 'Chandler' strawberries. Gainesville, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Plant vigor ^y (Jan 29)	Nutsedge (plants/m ²)		
				Through film Oct 8 May 18	Under May 18	
1 Untreated		1705 d ^w	2.5 d	21.5 a	8.5	16.1 bc
2 Methyl bromide /Pic (67/33)	390 kg	4131 a	10.0 a	0.0 b	0.0	0.9 c
3 Chloropicrin (Pic) ^z	340 kg	3311 abc	6.8 bc	5.0 b	4.5	1.3 c
4 1,3-D + 35 % Pic ^z	327 L	3541 ab	8.0 b	3.4 b	0.9	4.0 c
5 1,3-D + 17 % Pic ^z	327 L	3620 ab	6.8 bc	0.8 b	20.2	16.6 bc
6 Metam-Na ^z	300 L	2552 bcd	5.5 c	28.4 b	12.1	13.9 bc
7 Metam-Na + Pic ^z	300 L + 170 kg	2199 cd	4.8 c	5.0 b	1.3	6.3 c
8 Solarization ^x		----	1.0 d	0.0 b	0.0	45.7 ab
9 Solarization ^y		2710 bcd	5.5 c	0.4 b	0.0	49.3 a
10 Metam-Na + Pic + solarization ^y	300 L + 170 kg	3002 abcd	6.0 bc	0.0 b	0.5	44.8 ab

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear and due to excessive weed growth, fruit was not harvested.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^y Plant vigor ratings with 10 = maximum growth and 1 = 10 % of maximum growth.

Table 2. Effect of fumigant treatments on yield, fruit weight, and nutsedge counts of 'Chandler' strawberries. NFREC, Quincy, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Size (g/fruit)	Nutsedge (plants/m ²) ^y
Untreated		2417 c ^w	15.5 c	29.3 ab
Methyl bromide /Pic (67/33)	390 kg	3511 ab	17.0 ab	1.0 d
Chloropicrin (Pic) ^z	340 kg	4040 a	17.4 ab	20.2 abc
1,3-D + 35 % Pic ^z	327 L	3553 ab	17.1 ab	10.1 cd
1,3-D + 17 % Pic ^z	327 L	3333 ab	17.2 ab	13.2 bcd
Metam-Na + Pic ^z	300 L + 170 kg	3279 ab	16.9 abc	19.8 abc
Metam-Na ^z	300 L	2933 bc	16.1 bc	30.4 a
Dazomet ^z	440 kg	3620 ab	17.1 ab	33.7 a
Solarization ^x		815 d	13.4 d	0.1 d
Solarization ^y		3210 b	16.2 abc	0.2 d
Metam-Na + Pic + solarization ^y	300 L + 170 kg	3116 bc	16.1 bc	0.1 d
Dazomet +solarization ^y	440 kg	3543 ab	17.7 a	0.1 d

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^y Nutsedge shoots penetrating mulch counted on Sept. 30.

In general, the high incidence of pathogenic fungi, especially *S. rolfsii*, *F. oxysporum*, *P. aphanidermatum*, and *R. solani*, and the severity of root disease caused by them undoubtedly contributed to poor plant growth, early plant mortality, and low yields at Gainesville. Fumigation probably delay the time of infection by fungi dispersed into treated soil and allowed increased yields before pathogenic fungi reach high levels of colonization and cause severe disease.

The population densities of the highly pathogenic sting (*Belonolaimus longicaudatus*) nematode at the end of the season at Gainesville was low and not affected by treatment (data not shown).

In summary, early plant growth and yields at Gainesville were poorer than expected, probably due the high incidences of fungal root diseases and to excessive rainfall during Dec. to Mar. The yield with MBr-Pic was statistically similar to that with 1,3-dichloropropene + 17% Pic (C-17), C-35, Pic, and soil solarization + metam-Na-mulch painted black before transplanting. Yields were significantly lower with the check, metam Na, metam Na + Pic, and soil solarization-mulch painted before planting than with MBr-Pic. At Quincy, plant growth was excellent and yields were statistically similar with Pic, MBr-Pic (67:33), dazomet, solarization + dazomet-mulch painted black, C-17, C35, and metam-Na + Pic. Lowest yields were obtained with the untreated check and solarization-mulch not painted black before planting. Soil solarization with the mulch painted black suppressed nutsedge but regrowth occurred with the mulch left clear. At Gainesville, treatment had no effect on sting nematode (*Belonolaimus longicaudatus*) population densities extracted from soil samples or fungi populations on plant roots at the end of the season.

Literature Cited

Chase, C.A., T. R. Sinclair, S.J. Locascio, J.P. Gilreath, J.P. Jones, and D.W. Dickson. 1997. An evaluation of improved polyethylene films for cool-season soil solarization. Proc. Fla. State Hort. Soc. 110:326-329.

Locascio, S. J., S. M. Olson, C. A. Chase, T. R. Sinclair, D. W. Dickson, D. J. Mitchell, and D. O. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Proc. National Agric. Plastics Congress. 28:148-154.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used; such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: metam-Na + chloropicrin

[Insert Alternative]

Study: Strawberry production with alternatives to methyl bromide

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X _____

This alternative can be used in tomato, strawberry, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website?

Yes

No

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Locascio, Olson, Chase, Sinclair, Dickson, Mitchell
and Chellemi

3. Publication and Date of Publication

Proc of 1999 Annual International Research Conf. on
Methyl Bromide Alternatives, 1999

4. Location of research study

Florida

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

metam-Na + chloropicrin

6. Was crop yield measured in the study?

Yes X

No

7. Describe the effectiveness of the alternative in controlling pests in the study.

Similar results (not effective) would be expected in North Carolina in
control of yellow nutsedge by this alternative. Effectiveness was not
acceptable for control.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Similar results would be expected in North Carolina across strawberry, tomato,
cucurbit crops and pepper. Growers do not have access to a tillage
to incorporate this alternative.

Research Summary Table

Alternative: Metam-Na + ChloropicrinStudy: Locascio et al., 1999

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. a/ per area)	Pest 1: Nutsedge (no. per m ²) (penetrating plastic)						Pest 2: Nutsedge (no. per m ²) (under plastic)						Yield (flats/ha)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	untreated		6 WAT	22					6 WAT	16					1,705
2	methyl bromide +														
	chloropicrin		6 WAT	0					6 WAT	0.9					4,131
7	metam-Na +														
	chloropicrin		6 WAT	5					6 WAT	6.3					2,199

Comments:

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If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
metam-Na +	nutsedge	metam-Na	4.26	127	32	gal	\$ 4.00	\$ 15.00		100	1	\$ 143.00
chloropicrin		chloropicrin	liquid	151.3	3.6	gal	\$ 2.50	\$ 75.00	80	100	1	\$ 533.25
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 676.25

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

Metam-Na + Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a representative user.					
The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.					
Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.				
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.				
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.				
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.				
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.				
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the				
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.					
A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Strawberry	grade, time, market	flats (11 lbs.)	890.00	\$ 8.00	\$ 7,122.26
				Total Revenue	\$ 7,122.26
Comments:					

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

ID#

Metam-Na + Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25.00			\$ 15.00	Tractor with tillovator
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

03-0041

1999

Annual
International Research
Conference
On
Methyl Bromide
Alternatives
And Emissions Reductions

November 1 - 4, 1999

The DoubleTree Hotel
Mission Valley
7450 Hazard Center Drive
San Diego, California 92108

Sponsored by
Methyl Bromide Alternatives Outreach

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Crop Protection Coalition
U S Environmental Protection Agency
And
U S Department of Agriculture

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Support Provided by the UNEP TIE

STRAWBERRY PRODUCTION WITH ALTERNATIVES TO METHYL BROMIDE FUMIGATION

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Strawberries were transplanted in the fall of 1997 to polyethylene mulched beds in Gainesville on a Millhopper fine sand and in Quincy on an Orangeburg fine sandy loam to evaluate the effects of soil fumigants and solarization on fruit production and reported (Locascio, et al., 1999). Fumigant and solarization treatments were applied on Aug. 21 and 19, 1997, respectively. On selected plots, napropamide was applied at 4.8 kg/ha for weed control and fumigant metam-Na at 300 L/ha were rototilled into the bed. Soil fumigants were injected with two chisels per bed spaced 30 cm apart at a depth of 20 to 25 cm at 390 kg/ha 67 % MBr + 33 % Pic, 340 kg/ha Pic, 327 L/ha a C-17, and C-35, and 440 kg/ha dazomet. Drip tubing was placed on the beds before application of 38.1 μ m (1.5 mil) black polyethylene mulch or 102 μ m (4 mil) clear thermal infrared-absorbing film (AT Plastics, Inc., Edmonton, Canada). Soil temperature was measured at 0- to 25-cm depths in two plots mulched with black and in four plots mulched with the clear film (Chase et al., 1997). Some clear mulches (Table 1) were painted with black latex paint a week before transplanting. 'Chandler' was transplants on Oct.21 and Nov.7, respectively.

Transplants were sampled for fungal colonization of roots on 24 Oct. Fruits were harvested twice weekly, graded and weighed. Soil and plants were sampled for nematode and fungal populations at Gainesville at the end of the harvest season on May 18.

Fungi were isolated from the roots and crown tissue of every plant sampled before transplanting. VA mycorrhizal fungi were observed on 95% of the root samples. *Alternaria*, *Fusarium*, *Rhizoctonia*, *Trichoderma*, and an unknown pycnidial forming fungus were isolated from 5, 35, 25, 5, and 5% of the crown pieces, respectively. Although some species of *Alternaria*, *Fusarium*, and *Rhizoctonia* may cause root diseases, it was not possible to determine the source of pathogens isolated from roots during the growing season and at harvest.

Solar radiation and soil temperatures decreased over the measurement periods (60 days) from Aug. to Oct. Soil temperatures by late Sept. were insufficient to control nutsedge tubers or to kill emerged shoots trapped under the clear film. Maximum soil temperatures exceeding 45 C with the clear mulch at 10 cm occurred on less than 2 % of the days. By the sixth week of solarization at Gainesville, nutsedge density in the control treatment was 22 plants m⁻² (Table 1). Metam-Na + napropamide was the only treatment that failed to reduce the number of nutsedge plants penetrating the mulches. All other treatments significantly reduced nutsedge densities to levels that were statistically similar to that

with MBr-Pic. By Dec., it was apparent that painting the solarization film before transplanting was necessary. The clear film maintained soil temperatures that were sufficiently warm to promote the sprouting of tubers but not hot enough to cause foliar scorching of the shoots trapped under the film. The cooler temperatures apparently induced nutsedge dormancy since the nutsedge pressure was relatively low with all other treatments. By the end of the crop, nutsedge densities under the solarization films were greater than with the black films (Table 1).

At Gainesville, strawberry plant growth was slow, possibly due to the high occurrence of rainfall after transplanting. Rainfall exceeded average in each month from transplanting through Mar. Rainfall in Feb. was approximately three times the average. Plant vigor ratings were made on Jan. 29, 1998 (Table 1). Plant growth rating of plants with no treatment was only 2.5 on a rating of 1 (poor growth) to 10 (excellent growth) and was significantly greater with all treatments except that with the unpainted clear mulch solarization treatment. Marketable fruit yields were significantly higher with MBr-Pic than with no fumigant, metam-Na with and without Pic, and with the soil solarization treatment-mulch painted black before transplanting (Table 1). Total fruit yields in flats/ha were highest with MBr-Pic (4,131), C-17 (3,620), C-35 (3,541), Pic (3,311), and soil solarization with metam-Na-mulch painted (3,002), and significantly lower with metam-Na (2,552), soil solarization-mulch painted (2,710), metam-Na + Pic (2,199) and the check (1,705). Fruit was not obtained with soil solarization-clear mulch not painted. Weed growth under the clear mulch was extensive and picked the mulch up 7.5 to 15 cm over the soil; thus, strawberry plants did not survive the weed competition.

At Quincy, strawberry plant growth was excellent and fruit yields are shown in Table 2. Total fruit yield (in flats/ha) was highest with Pic (4,040), MBr-Pic (3,511), C-35 (3,553), C-17 (3,333), Metam-Na + Pic (3,279), Dazomet (3,620), and Dazomet + solarization-mulch painted (3,543). Lower yields were obtained with solarization-mulch painted (3,210) and with metam-Na + Pic (3,116) and with no fumigant (2,417). The lowest yield was obtained with solarization-mulch not painted (815). Fruit size response to fumigant treatment was similar to that obtained for total yield. Marketable fruit were larger with treatments that resulted in higher yield and smaller with treatments that resulted in lower yields. Nutsedge counts were made on Sept. 30 and data are shown in Table 2. Nutsedge control was excellent with MBr-Pic, and with all solarization treatments, intermediate with C-17 and C-35 + napropamide, and poorest with Pic, metam-Na-Pic and dazomet each + napropamide and with the untreated check.

Roots and crowns of strawberry plants in all soil treatments at the end of the season were colonized by a wide array and diversity of fungi, and high incidences of colonization were attained by many of them. Fungi in 18 genera were isolated from roots. Incidences of infection of plants by potentially damaging pathogenic fungi included 29-59% with *Alternaria* spp., 13-42% with *Sclerotium rolfsii*, 50-83% with *Colletotrichum* spp., 13-59% with *Curvularia* spp., 75-96% with *Fusarium oxysporum*, 4-17% with *Macrophomina phaseolina*, 29-79% with *Phoma* spp., 17-42% with *Pythium aphanidermatum*, 4-17% with other *Pythium* spp., and 67-92% with *Rhizoctonia solani*.

Table 1. Effect of fumigant treatments on fruit yield, plant vigor, and nutsedge counts of 'Chandler' strawberries. Gainesville, FL. 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Plant vigor ^y (Jan 29)	Nutsedge (plants/m ²)		
				Through film film Oct 8 May 18	Under May 18	
1 Untreated		1705 d ^w	2.5 d	21.5 a	8.5	16.1 bc
2 Methyl bromide /Pic (67/33)	390 kg	4131 a	10.0 a	0.0 b	0.0	0.9 c
3 Chloropicrin (Pic) ^z	340 kg	3311 abc	6.8 bc	5.0 b	4.5	1.3 c
4 1,3-D + 35 % Pic ^z	327 L	3541 ab	8.0 b	3.4 b	0.9	4.0 c
5 1,3-D + 17 % Pic ^z	327 L	3620 ab	6.8 bc	0.8 b	20.2	16.6 bc
6 Metam-Na ^z	300 L	2552 bcd	5.5 c	28.4 b	12.1	13.9 bc
7 Metam-Na + Pic ^z	300 L + 170 kg	2199 cd	4.8 c	5.0 b	1.3	6.3 c
8 Solarization ^x		---	1.0 d	0.0 b	0.0	45.7 ab
9 Solarization ^y		2710 bcd	5.5 c	0.4 b	0.0	49.3 a
10 Metam-Na + Pic + solarization ^y	300 L + 170 kg	3002 abcd	6.0 bc	0.0 b	0.5	44.8 ab

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear and due to excessive weed growth, fruit was not harvested.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^y Plant vigor ratings with 10 = maximum growth and 1 = 10 % of maximum growth.

Table 2. Effect of fumigant treatments on yield, fruit weight, and nutsedge counts of 'Chandler' strawberries. NFREC, Quincy, FL 1997-98

Treatment	Rate/ha	Yield (flats/ha)	Size (g/fruit)	Nutsedge (plants/m ²) ^y
Untreated		2417 c ^w	15.5 c	29.3 ab
Methyl bromide /Pic (67/33)	390 kg	3511 ab	17.0 ab	1.0 d
Chloropicrin (Pic) ^z	340 kg	4040 a	17.4 ab	20.2 abc
1,3-D + 35 % Pic ^z	327 L	3553 ab	17.1 ab	10.1 cd
1,3-D + 17 % Pic ^z	327 L	3333 ab	17.2 ab	13.2 bcd
Metam-Na + Pic ^z	300 L + 170 kg	3279 ab	16.9 abc	19.8 abc
Metam-Na ^z	300 L	2933 bc	16.1 bc	30.4 a
Dazomet ^z	440 kg	3620 ab	17.1 ab	33.7 a
Solarization ^x		815 d	13.4 d	0.1 d
Solarization ^y		3210 b	16.2 abc	0.2 d
Metam-Na + Pic + solarization ^y	300 L + 170 kg	3116 bc	16.1 bc	0.1 d
Dazomet +solarization ^y	440 kg	3543 ab	17.7 a	0.1 d

^z Napropamide applied at 4.4 kg/ha.

^y Mulch painted black before planting.

^x Mulch left clear.

^w Mean separation Duncan's Multiple Range Test, 5 % level.

^y Nutsedge shoots penetrating mulch counted on Sept. 30.

In general, the high incidence of pathogenic fungi, especially *S. rolfii*, *F. oxysporum*, *P. aphanidermatum*, and *R. solani*, and the severity of root disease caused by them undoubtedly contributed to poor plant growth, early plant mortality, and low yields at Gainesville. Fumigation probably delay the time of infection by fungi dispersed into treated soil and allowed increased yields before pathogenic fungi reach high levels of colonization and cause severe disease.

The population densities of the highly pathogenic sting (*Belonolaimus longicaudatus*) nematode at the end of the season at Gainesville was low and not affected by treatment (data not shown).

In summary, early plant growth and yields at Gainesville were poorer than expected, probably due the high incidences of fungal root diseases and to excessive rainfall during Dec. to Mar. The yield with MBr-Pic was statistically similar to that with 1,3-dichloropropene + 17% Pic (C-17), C-35, Pic, and soil solarization + metam-Na-mulch painted black before transplanting. Yields were significantly lower with the check, metam Na, metam Na + Pic, and soil solarization-mulch painted before planting than with MBr-Pic. At Quincy, plant growth was excellent and yields were statistically similar with Pic, MBr-Pic (67:33), dazomet, solarization + dazomet-mulch painted black, C-17, C35, and metam-Na + Pic. Lowest yields were obtained with the untreated check and solarization-mulch not painted black before planting. Soil solarization with the mulch painted black suppressed nutsedge but regrowth occurred with the mulch left clear. At Gainesville, treatment had no effect on sting nematode (*Belonolaimus longicaudatus*) population densities extracted from soil samples or fungi populations on plant roots at the end of the season.

Literature Cited

Chase, C.A., T. R. Sinclair, S.J. Locascio, J.P. Gilreath, J.P. Jones, and D.W. Dickson. 1997. An evaluation of improved polyethylene films for cool-season soil solarization. Proc. Fla. State Hort. Soc. 110:326-329.

Locascio, S. J., S. M. Olson, C. A. Chase, T. R. Sinclair, D. W. Dickson, D. J. Mitchell, and D. O. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Proc. National Agric. Plastics Congress. 28:148-154.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: met am-Na

[Insert Alternative]

Study: Fumigant/herbicide combinations in tomato

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted	<u>X</u>
1b. Township caps	<u> </u>
1c. Alternative not acceptable in consuming country	<u> </u>
1d. Other (Please describe)	<u> </u>

These alternatives can be used in tomato, pepper, strawberry
and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

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ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

Section II. Existing Research Studies on Alternatives to Methyl Bromide

1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Culpepper

3. Publication and Date of Publication NOT PUBLISHED

4. Location of research study Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
metam-Na

6. Was crop yield measured in the study? Yes _____ No X

7. Describe the effectiveness of the alternative in controlling pests in the study.
Not effective in controlling nutsedge (yellow).

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

Similar results would be expected in North Carolina. Most growers
do not have access to a tractor mounted tillage vator. Similar results
would be expected across crops.

Research Summary Table

Alternative: Metam-NaStudy: Culpepper (unpublished)

Provide one summary table for each study being described.															
Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.															
Col. A: Treatment Number	List the treatment number from the research study you are citing.														
Col. B: Treatment	List what type of pest control method was used.														
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.														
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).														
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.														
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).														
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.														
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.															
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. al per area)	Pest 1: Percent Yellow Nutsedge Control						Pest 2						Yield (units/area)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	methyl bromide	375 lbs./acre	3 WAT	100											
16	metam-Na	56 gal/acre	3 WAT	61											
46	nontreated		3 WAT	0											
Comments: WAT = weeks after treatment; yield was not determined in study.															

If a consortium is submitting this application, the data for this table should reflect a representative user.													
Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.												
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.												
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.												
Col. D: Formulation	Enter the formulation or the % of active ingredient.												
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.												
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.												
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.												
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.												
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.												
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.												
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.													
A	B	C	D	E	F	G	H	I	J	K	L	M	
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)	
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)							
metam-Na +	nutsedge	metam-Na	4.28 HL	564.3	56	gal	\$ 4.00	\$ 90.00	80	100	1	\$ 394.00	
Non-Chemical Pest Control	Target Pests	Description										Cost/area	
											Total	\$ 394.00	
Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.													

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Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a <i>representative</i> user.					
The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.					
Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.				
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.				
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.				
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.				
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.				
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the				
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.					
A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 lb.)		\$ 8.25	
				Total Revenue	*
Comments: * = could not be determined because yield was not determined in the study.					

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Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item.	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	25.00			\$ 15.00	Tractor with tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

N. C. State University

Trial ID: Study Dir.:
Location: Investigator: Stanley Culpepper

GENERAL TRIAL INFORMATION

Investigator: Culpepper/Langston Title: Extension
Affiliation: UGA

TRIAL LOCATION

City: Douglas Trial Status: completed
State/Prov.: GA Trial Reliability: fair
Country: USA Initiation Date: Mar-21-02

Conducted Under GLP (Y/N): N

Conducted Under GEP (Y/N): N

CROP AND WEED DESCRIPTION

Weed	Code	Common Name	Scientific Name
1.	CYPES	yellow nutsedge	
2.	AMAPA	Palmer amaranth	

Crop 1: tomat tomato

Variety: BHN 444

Planting Method: transplant

Rate: 1 20"

Depth: 2.5 "

Row Spacing: 6 ft

Seed Bed: bed/black plastic

Soil Moisture: drip

SITE AND DESIGN

Plot Width, Unit: 10 FT

Plot Length, Unit: 40 FT

Reps: 4

Site Type: on-farm

Tillage Type: conventional

Study Design: FACTORIAL

CROP STAGE AT EACH APPLICATION

	A
Crop 1 Code, Stage:	tomat
Stage Scale:	PRE

WEED STAGE AT EACH APPLICATION

	A
Weed 1 Code, Stage:	CYPES
Stage Scale:	PRE
Weed 2 Code, Stage:	AMAPA
Stage Scale:	PRE

N. C. State University

Trial ID:

Study Dir.:

Location:

Investigator: Stanley Culpepper

Crop Code	tomato	tomato	CYPES	CYPES	AMAPA	AMAPA
Rating Data Type	injury	injury	control	control	control	control
Rating Unit	percent	percent	percent	percent	percent	percent
Rating Date	Apr-12-02	May-06-02	Apr-12-02	May-06-02	Apr-12-02	May-06-02
Weed Density, Unit	6 ydsq	7 ydsq	4 ydsq	4 ydsq	4 ydsq	4 ydsq
Trt Treatment	Rate	Grow				
No. Name	Unit	Stg				
1 MBR (375 lb/A) no herbicide	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
2 MBR (375 lb/A) Dual (1 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
3 MBR (375 lb/A) Sandeia (0.024 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
4 MBR (375 lb/A) Sulfentrazone (0.2 lb ai)	7.5 d-h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
5 MBR (375 lb/A) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	3.0 fgh	0.0 g	100.0 a	100.0 a	95.5 a-d	100.0 a
6 Pic (282 lb/A) no herbicide	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
7 Pic (282 lb/A) Dual (1 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
8 Pic (282 lb/A) Sandeia (0.024 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
9 Pic (282 lb/A) Sulfentrazone (0.2 lb ai)	10.0 d-g	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
10 Pic (282 lb/A) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	6.3 d-h	0.0 g	100.0 a	100.0 a	98.0 a	100.0 a
11 T2 (10 G) fb Pic (150 lb) no herbicide	0.0 h	0.0 g	91.3 abc	93.8 a-e	93.8 a-d	95.0 abc
12 T2 (10 G) fb Pic (150 lb) Dual (1 lb A/A)	0.0 h	2.5 fg	95.8 ab	95.0 a-e	96.5 abc	100.0 a
13 T2 (10 G) fb Pic (150 lb) Sandeia (0.024 lb A/A)	0.0 h	2.5 fg	96.5 ab	92.5 a-f	96.5 abc	90.0 a-d
14 T2 (10 G) fb Pic (150 lb) Sulfentrazone (0.2 lb ai)	10.0 d-g	2.5 fg	96.5 ab	93.3 a-e	96.5 abc	97.5 ab
15 T2 (10 G) fb Pic (150 lb) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	9.3 d-h	2.5 fg	96.5 ab	90.8 a-g	96.5 abc	100.0 a
16 Vapam (56 G) no herbicide	12.5 b-e	12.5 a-e	61.3 ijk	62.5 o-r	82.5 efg	95.0 abc
17 Vapam (56 G) Dual (1 lb A/A)	11.3 c-f	12.5 a-e	73.8 e-i	71.3 k-p	95.0 a-d	97.5 ab
18 Vapam (56 G) Sandeia (0.024 lb A/A)	6.3 d-h	12.5 a-e	72.5 e-i	68.8 m-p	91.3 a-e	100.0 a
19 Vapam (56 G) Sulfentrazone (0.2 lb ai)	23.8 a	12.5 a-e	85.0 b-e	86.5 b-i	95.0 a-d	95.0 abc
20 Vapam (56 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	15.0 a-d	10.0 a-f	71.3 f-i	87.5 a-h	91.3 a-e	95.0 abc
21 Vapam (75 G) no herbicide	2.5 fgh	15.0 abc	62.5 ijk	63.8 n-r	82.5 efg	95.0 abc

N. C. State University

Crop Code Rating Data Type Rating Unit Rating Date Weed Density, Unit	tomato injury percent Apr-12-02	tomato injury percent May-06-02	CYPES control percent Apr-12-02 6 ydsq	CYPES control percent May-06-02 7 ydsq	AMAPA control percent Apr-12-02 4 ydsq	AMAPA control percent May-06-02 4 ydsq
Trt Treatment No. Name Rate Unit Grow Stg						
22 Vapam (75 G) Dual (1 lb A/A)	6.3 d-h	15.0 abc	66.3 hij	71.3 k-p	93.8 a-d	100.0 a
23 Vapam (75 G) Sandeia (0.024 lb A/A)	8.8 d-h	13.8 a-d	90.0 a-d	98.8 ab	88.8 a-f	100.0 a
24 Vapam (75 G) Sulfentrazone (0.2 lb ai)	21.3 ab	16.3 ab	84.8 b-e	68.8 m-p	95.0 a-d	92.5 a-d
25 Vapam (75 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	12.5 b-e	15.0 abc	88.8 a-d	97.5 abc	93.8 a-d	100.0 a
26 Telone C35 (18 G) no herbicide	0.0 h	7.5 b-g	52.5 k	52.5 r	76.3 gh	71.3 fg
27 Telone C35 (18 G) Dual (1 lb A/A)	0.0 h	7.5 b-g	67.5 g-j	73.8 i-o	91.0 a-e	96.3 abc
28 Telone C35 (18 G) Sandeia (0.024 lb A/A)	0.0 h	7.5 b-g	73.8 e-i	71.3 k-p	87.5 b-f	92.5 a-d
29 Telone C35 (18 G) Sulfentrazone (0.2 lb ai)	5.0 e-h	7.5 b-g	84.8 b-e	80.0 f-m	91.5 a-e	91.3 a-d
30 Telone C35 (18 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	0.0 h	7.5 b-g	78.8 c-h	76.3 h-n	93.5 a-d	98.8 a
31 Telone C35 (36 G) no herbicide	0.0 h	3.8 efg	80.8 c-g	85.0 c-j	72.5 h	75.0 efg
32 Telone C35 (36 G) Dual (1 lb A/A)	0.0 h	3.8 efg	82.0 c-f	82.5 e-l	95.0 a-d	90.0 a-d
33 Telone C35 (36 G) Sandeia (0.024 lb A/A)	2.5 fgh	3.8 efg	77.0 d-h	86.3 b-i	90.0 a-f	83.8 c-f
34 Telone C35 (36 G) Sulfentrazone (0.2 lb ai)	9.3 d-h	3.8 efg	89.8 a-d	85.0 c-j	86.3 def	85.0 b-e
35 Telone C35 (36 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	8.8 d-h	3.8 efg	89.8 a-d	92.5 a-f	87.5 b-f	92.5 a-d
36 Telone C35 (18 G) Vapam (37 G) no herbicide	2.5 fgh	6.8 c-g	62.5 ijk	55.0 qr	81.3 fgh	65.0 g
37 Telone C35 (18 G) Vapam (37 G) Dual (1 lb A/A)	0.0 h	6.8 c-g	71.3 f-i	67.5 m-q	92.5 a-d	87.5 a-e
38 Telone C35 (18 G) Vapam (37 G) Sandeia (0.024 lb A/A)	2.5 fgh	6.8 c-g	74.5 e-i	78.8 g-m	93.8 a-d	95.0 abc
39 Telone C35 (18 G) Vapam (37 G) Sulfentrazone (0.2 lb ai)	1.3 gh	6.8 c-g	77.5 d-h	71.3 k-p	95.0 a-d	98.8 a
40 Telone C35 (18 G) Vapam (37 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	3.8 e-h	6.8 c-g	90.0 a-d	96.3 a-d	95.0 a-d	97.5 ab
41 Telone C35 (18 G) Vapam (56 G) no herbicide	2.5 fgh	5.5 d-g	67.5 g-j	72.5 j-o	91.3 a-e	93.8 abc

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Crop Code	tomato	tomato	CYPES	CYPES	AMAPA	AMAPA
Rating Data Type	injury	injury	control	control	control	control
Rating Unit	percent	percent	percent	percent	percent	percent
Rating Date	Apr-12-02	May-06-02	Apr-12-02	May-06-02	Apr-12-02	May-06-02
Weed Density, Unit	6 ydsq	7 ydsq	4 ydsq	4 ydsq	4 ydsq	4 ydsq
Trt Treatment	Rate	Grow				
No. Name	Unit	Stg				
42 Telone C35 (18 G) Vapam (56 G) Dual (1 lb A/A)	2.5 fgh	5.5 d-g	56.3 jk	58.8 pqr	86.3 def	93.8 abc
43 Telone C35 (18 G) Vapam (56 G) Sanda (0.024 lb A/A)	3.8 e-h	5.5 d-g	81.5 c-f	90.0 a-g	95.0 a-d	88.8 a-d
44 Telone C35 (18 G) Vapam (56 G) Sulfentrazone (0.2 lb ai)	20.0 abc	5.5 d-g	88.8 a-d	87.0 a-h	92.5 a-d	88.8 a-d
45 Telone C35 (18 G) Vapam (56 G) Dual (1 lb A/A) Sanda (0.24 lb A/A)	3.8 e-h	5.5 d-g	62.5 ijk	65.0 n-r	95.0 a-d	91.3 a-d
46 non-treated no herbicide	0.0 h	18.8 a	0.0 l	0.0 s	0.0 i	0.0 h
47 non-treated Dual (1 lb A/A)	7.5 d-h	18.8 a	82.0 c-f	87.5 a-h	93.8 a-d	95.0 abc
48 non-treated Sanda (0.024 lb A/A)	5.0 e-h	18.8 a	85.0 b-e	90.0 a-g	88.0 b-f	95.0 abc
49 non-treated Sulfentrazone (0.2 lb ai)	11.3 c-f	18.8 a	82.0 c-f	70.0 l-p	82.3 efg	80.0 def
50 non-treated Dual (1 lb A/A) Sanda (0.24 lb A/A)	5.0 e-h	18.8 a	83.8 b-f	83.8 d-k	87.3 c-f	90.0 a-d
LSD (P=.05)	9.41	9.03	13.37	13.14	9.62	13.48
Standard Deviation	6.72	6.45	9.55	9.38	6.87	9.63
CV	127.89	90.54	11.72	11.44	7.63	10.49
Replicate F	1.817	5.057	3.672	2.102	3.232	2.001
Replicate Prob(F)	0.1467	0.0023	0.0137	0.1025	0.0242	0.1164
Treatment F	3.153	3.586	13.933	15.026	17.127	10.154
Treatment Prob(F)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means followed by same letter do not significantly differ (P=.05, LSD)

Trial Comments

GENERAL COMMENTS: Herbicides applied after bed shaping and just prior to laying plastic. Herbicides applied at 25 GPA with 11002 flat fan nozzles at 3 mph. Fumigants were applied with various rigs: metam sodium applied on top of soil and rototilled in top 4 inches; Telone 2 and Telone C35 shanked applied 12 to 14 inches deep with rototiller; Chloropicrin and methyl bromide applied with super bedder injecting fumigant 6 to 8 inches deep.

OBJECTIVE: Determine crop and nutsedge response to various methyl bromide alternatives.

RESULTS:

Crop Tolerance:

- 1) A significant fumigant by herbicide interaction was not noted.
- 2) Sulfentrazone, pooled over all fumigants, stunted tomato growth 12 percent at 3 WAT (weeks after applying treatments). By 6 WAT, no differences in tomato injury by herbicides was noted.
- 3) At 3 WAT, stunting from metam was greater than from any other fumigant option.

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4) By 6 WAT, stunting was greatest with metam sodium only or no fumigant. Stunting late in the season may have been a response to nematodes.

Weed Control:

Yellow nutsedge (fumigant):

1. Biologically, fumigant main effects were of the greatest significant value. Therefore, results are pooled over herbicide options.
2. Methyl bromide provided complete control of yellow nutsedge. Control was 33 to 34% more effective than the no fumigant option when pooled over the herbicide option.
3. Chloropicrin (282 lb) was the only fumigant option as effective as methyl bromide throughout the season.
4. Telone 2 followed by chloropicrin was 5 to 7% less effective than bromide and 27 to 29% more effective than the no fumigant option.
5. Telone C35 at 36 GPA was 14 to 18% less effective than bromide and 17 to 20% more effective than the no fumigant option.
6. Metam alone or in combination with Telone C35 were 20 to 29% less effective than methyl bromide and only 5 to 14% more effective than the no fumigant option.
7. Telone C35 at 18 GPA was 29% less effective than methyl bromide and no more effective than the no fumigant option.

Yellow nutsedge (herbicide)

1. Biologically, herbicide main effects were of the greatest significant value. Therefore, results are pooled over fumigant options.
2. All herbicide options improved control by at least 11% compared to the no herbicide option.
3. Generally, sulfentrazone, Sandea, and Dual plus Sandea provided similar control and control was slightly better than Dual applied alone.

Palmer amaranth (fumigant):

1. Pooled over herbicide options, all fumigants improved Palmer control by at least 14%.
2. Methyl bromide, chloropicrin options, and metam treatments were generally the most effective options.

Palmer amaranth (herbicides):

1. Pooled over fumigant options, the no herbicide treatment provided 77 to 79% control. All herbicides improved control.
2. Control was similar among all herbicide treatments.

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3-A(2)1

For EPA Use Only

ID#

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + chloropicrin

[Insert Alternative]

Study: Fumigant/herbicide combinations in

[Insert Study Title]

tomato

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

This alternative can be used in tomato, pepper, strawberry and
cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide****Section II. Existing Research Studies on Alternatives to Methyl Bromide**1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Culpepper3. Publication and Date of Publication not published4. Location of research study Georgia5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.
1,3-D6. Was crop yield measured in the study? Yes _____ No X

7. Describe the effectiveness of the alternative in controlling pests in the study.

Not effective

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

We would expect similar results in North Carolina. Growers would not use this alternative because of its ineffectiveness. Similar results would be expected in strawberries, pepper and cucurbit crops.

Research Summary Table

Alternative: 1,3-D + ChloropicrinStudy: Culpepper (unpublished)

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. at per area)	Pest 1: Percent Yellow Nutsedge Control						Pest 2						Yield (units/area)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	methyl bromide	375 lbs./acre	3 WAT	100	6 WAT	100									
26	1,3-D +	18 gal	3 WAT	52.5	6 WAT	52.5									
	chloropicrin														
46	nontreated		3 WAT	0	6 WAT	0									

Comments:

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Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

A	B	C	D	E	F	G	H	I	J	K	L	M

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

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The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle.

Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.

Enter the unit of measurement for your crop/commodity.

Enter the number of units of crop/commodity produced per area for that price factor identified.

Enter the average 2001 prices received by the users for that crop/commodity and price factor.

In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

A

45

C

4

F

Price Factors
(grade, time, market)

Unit of
Crop/Commodity
(e.g., pounds, bushels)

Crop/Commodity Yield
(Units per area)

Price
(per unit of
crop/commodity)

Revenue
(per area)

Tomato

grade, time, market

boxes (25 lb.)

★

\$ 8.25

1

Total Revenue

OMB Control # 2060-0482

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

1,3-D + Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling					
Total Custom per Area			User Total per area		

Comments: No change

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N. C. State University

Trial ID: Study Dir.:
 Location: Investigator: Stanley Culpepper

GENERAL TRIAL INFORMATION

Investigator: Culpepper/Langston Title: Extension
 Affiliation: UGA

TRIAL LOCATION

City: Douglas Trial Status: completed
 State/Prov.: GA Trial Reliability: fair
 Country: USA Initiation Date: Mar-21-02

Conducted Under GLP (Y/N): N

Conducted Under GEP (Y/N): N

CROP AND WEED DESCRIPTION

Weed	Code	Common Name	Scientific Name
1.	CYPES	yellow nutsedge	
2.	AMAPA	Palmer amaranth	

Crop 1: tomat tomato

Variety: BHN 444

Planting Method: transplant

Rate: 1 20"

Depth: 2.5 "

Row Spacing: 6 ft

Seed Bed: bed/black plastic

Soil Moisture: drip

SITE AND DESIGN

Plot Width, Unit: 10 FT

Plot Length, Unit: 40 FT

Reps: 4

Site Type: on farm

Tillage Type: conventional

Study Design: FACTORIAL

CROP STAGE AT EACH APPLICATION

	A
Crop 1 Code, Stage:	tomat
Stage Scale:	PRE

WEED STAGE AT EACH APPLICATION

	A
Weed 1 Code, Stage:	CYPES
Stage Scale:	PRE
Weed 2 Code, Stage:	AMAPA
Stage Scale:	PRE

N. C. State University

Trial ID:

Study Dir.:

Location:

Investigator: Stanley Culpepper

Crop Code	tomato	tomato	CYPES	CYPES	AMAPA	AMAPA
Rating Data Type	injury	injury	control	control	control	control
Rating Unit	percent	percent	percent	percent	percent	percent
Rating Date	Apr-12-02	May-06-02	Apr-12-02	May-06-02	Apr-12-02	May-06-02
Weed Density, Unit	6 ydsq	7 ydsq	4 ydsq	4 ydsq	4 ydsq	4 ydsq
Trt Treatment	Rate	Grow				
No. Name	Unit	Stg				
1 MBR (375 lb/A) no herbicide	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
2 MBR (375 lb/A) Dual (1 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
3 MBR (375 lb/A) Sandeia (0.024 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
4 MBR (375 lb/A) Sulfentrazone (0.2 lb ai)	7.5 d-h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
5 MBR (375 lb/A) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	3.0 fgh	0.0 g	100.0 a	100.0 a	95.5 a-d	100.0 a
6 Pic (282 lb/A) no herbicide	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
7 Pic (282 lb/A) Dual (1 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
8 Pic (282 lb/A) Sandeia (0.024 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
9 Pic (282 lb/A) Sulfentrazone (0.2 lb ai)	10.0 d-g	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
10 Pic (282 lb/A) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	6.3 d-h	0.0 g	100.0 a	100.0 a	98.0 a	100.0 a
11 T2 (10 G) fb Pic (150 lb) no herbicide	0.0 h	0.0 g	91.3 abc	93.8 a-e	93.8 a-d	95.0 abc
12 T2 (10 G) fb Pic (150 lb) Dual (1 lb A/A)	0.0 h	2.5 fg	95.8 ab	95.0 a-e	96.5 abc	100.0 a
13 T2 (10 G) fb Pic (150 lb) Sandeia (0.024 lb A/A)	0.0 h	2.5 fg	96.5 ab	92.5 a-f	96.5 abc	90.0 a-d
14 T2 (10 G) fb Pic (150 lb) Sulfentrazone (0.2 lb ai)	10.0 d-g	2.5 fg	96.5 ab	93.3 a-e	96.5 abc	97.5 ab
15 T2 (10 G) fb Pic (150 lb) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	9.3 d-h	2.5 fg	96.5 ab	90.8 a-g	96.5 abc	100.0 a
16 Vapam (56 G) no herbicide	12.5 b-e	12.5 a-e	61.3 ijk	62.5 o-r	82.5 efg	95.0 abc
17 Vapam (56 G) Dual (1 lb A/A)	11.3 c-f	12.5 a-e	73.8 e-i	71.3 k-p	95.0 a-d	97.5 ab
18 Vapam (56 G) Sandeia (0.024 lb A/A)	6.3 d-h	12.5 a-e	72.5 e-i	68.8 m-p	91.3 a-e	100.0 a
19 Vapam (56 G) Sulfentrazone (0.2 lb ai)	23.8 a	12.5 a-e	85.0 b-e	86.5 b-i	95.0 a-d	95.0 abc
20 Vapam (56 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	15.0 a-d	10.0 a-f	71.3 f-i	87.5 a-h	91.3 a-e	95.0 abc
21 Vapam (75 G) no herbicide	2.5 fgh	15.0 abc	62.5 ijk	63.8 n-r	82.5 efg	95.0 abc

N. C. State University

Crop Code Rating Data Type Rating Unit Rating Date Weed Density, Unit				tomato injury percent Apr-12-02	tomato injury percent May-06-02	CYPES control percent Apr-12-02 6 ydsq	CYPES control percent May-06-02 7 ydsq	AMAPA control percent Apr-12-02 4 ydsq	AMAPA control percent May-06-02 4 ydsq
Trt No.	Treatment Name	Rate	Grow Unit Stg						
22	Vapam (75 G) Dual (1 lb A/A)			6.3 d-h	15.0 abc	66.3 hij	71.3 k-p	93.8 a-d	100.0 a
23	Vapam (75 G) Sandea (0.024 lb A/A)			8.8 d-h	13.8 a-d	90.0 a-d	98.8 ab	88.8 a-f	100.0 a
24	Vapam (75 G) Sulfentrazone (0.2 lb ai)			21.3 ab	16.3 ab	84.8 b-e	68.8 m-p	95.0 a-d	92.5 a-d
25	Vapam (75 G) Dual (1 lb A/A) Sandea (0.24 lb A/A)			12.5 b-e	15.0 abc	88.8 a-d	97.5 abc	93.8 a-d	100.0 a
26	Telone C35 (18 G) no herbicide			0.0 h	7.5 b-g	52.5 k	52.5 r	76.3 gh	71.3 fg
27	Telone C35 (18 G) Dual (1 lb A/A)			0.0 h	7.5 b-g	67.5 g-j	73.8 i-o	91.0 a-e	96.3 abc
28	Telone C35 (18 G) Sandea (0.024 lb A/A)			0.0 h	7.5 b-g	73.8 e-i	71.3 k-p	87.5 b-f	92.5 a-d
29	Telone C35 (18 G) Sulfentrazone (0.2 lb ai)			5.0 e-h	7.5 b-g	84.8 b-e	80.0 f-m	91.5 a-e	91.3 a-d
30	Telone C35 (18 G) Dual (1 lb A/A) Sandea (0.24 lb A/A)			0.0 h	7.5 b-g	78.8 c-h	76.3 h-n	93.5 a-d	98.8 a
31	Telone C35 (36 G) no herbicide			0.0 h	3.8 efg	80.8 c-g	85.0 c-j	72.5 h	75.0 efg
32	Telone C35 (36 G) Dual (1 lb A/A)			0.0 h	3.8 efg	82.0 c-f	82.5 e-i	95.0 a-d	90.0 a-d
33	Telone C35 (36 G) Sandea (0.024 lb A/A)			2.5 fgh	3.8 efg	77.0 d-h	86.3 b-i	90.0 a-f	83.8 c-f
34	Telone C35 (36 G) Sulfentrazone (0.2 lb ai)			9.3 d-h	3.8 efg	89.8 a-d	85.0 c-j	86.3 def	85.0 b-e
35	Telone C35 (36 G) Dual (1 lb A/A) Sandea (0.24 lb A/A)			8.8 d-h	3.8 efg	89.8 a-d	92.5 a-f	87.5 b-f	92.5 a-d
36	Telone C35 (18 G) Vapam (37 G) no herbicide			2.5 fgh	6.8 c-g	62.5 ijk	55.0 qr	81.3 fgh	65.0 g
37	Telone C35 (18 G) Vapam (37 G) Dual (1 lb A/A)			0.0 h	6.8 c-g	71.3 f-i	67.5 m-q	92.5 a-d	87.5 a-e
38	Telone C35 (18 G) Vapam (37 G) Sandea (0.024 lb A/A)			2.5 fgh	6.8 c-g	74.5 e-i	78.8 g-m	93.8 a-d	95.0 abc
39	Telone C35 (18 G) Vapam (37 G) Sulfentrazone (0.2 lb ai)			1.3 gh	6.8 c-g	77.5 d-h	71.3 k-p	95.0 a-d	98.8 a
40	Telone C35 (18 G) Vapam (37 G) Dual (1 lb A/A) Sandea (0.24 lb A/A)			3.8 e-h	6.8 c-g	90.0 a-d	96.3 a-d	95.0 a-d	97.5 ab
41	Telone C35 (18 G) Vapam (56 G) no herbicide			2.5 fgh	5.5 d-g	67.5 g-j	72.5 j-o	91.3 a-e	93.8 abc

N. C. State University

Crop Code Rating Data Type Rating Unit Rating Date Weed Density, Unit	tomato injury percent Apr-12-02	tomato injury percent May-06-02	CYPES control percent Apr-12-02 6 ydsq	CYPES control percent May-06-02 7 ydsq	AMAPA control percent Apr-12-02 4 ydsq	AMAPA control percent May-06-02 4 ydsq
Trt Treatment No. Name Rate Unit Grow Stg						
42 Telone C35 (18 G) Vapam (56 G) Dual (1 lb A/A)	2.5 fgh	5.5 d-g	56.3 jk	58.8 pqr	86.3 def	93.8 abc
43 Telone C35 (18 G) Vapam (56 G) Sandeia (0.024 lb A/A)	3.8 e-h	5.5 d-g	81.5 c-f	90.0 a-g	95.0 a-d	88.8 a-d
44 Telone C35 (18 G) Vapam (56 G) Sulfentrazone (0.2 lb ai)	20.0 abc	5.5 d-g	88.8 a-d	87.0 a-h	92.5 a-d	88.8 a-d
45 Telone C35 (18 G) Vapam (56 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)	3.8 e-h	5.5 d-g	62.5 ijk	65.0 n-r	95.0 a-d	91.3 a-d
46 non-treated no herbicide	0.0 h	18.8 a	0.0 i	0.0 s	0.0 i	0.0 h
47 non-treated Dual (1 lb A/A)	7.5 d-h	18.8 a	82.0 c-f	87.5 a-h	93.8 a-d	95.0 abc
48 non-treated Sandeia (0.024 lb A/A)	5.0 e-h	18.8 a	85.0 b-e	90.0 a-g	88.0 b-f	95.0 abc
49 non-treated Sulfentrazone (0.2 lb ai)	11.3 c-f	18.8 a	82.0 c-f	70.0 l-p	82.3 efg	80.0 def
50 non-treated Dual (1 lb A/A) Sandeia (0.24 lb A/A)	5.0 e-h	18.8 a	83.8 b-f	83.8 d-k	87.3 c-f	90.0 a-d
LSD (P=.05)	9.41	9.03	13.37	13.14	9.62	13.48
Standard Deviation	6.72	6.45	9.55	9.38	6.87	9.63
CV	127.89	90.54	11.72	11.44	7.63	10.49
Replicate F	1.817	5.057	3.672	2.102	3.232	2.001
Replicate Prob(F)	0.1467	0.0023	0.0137	0.1025	0.0242	0.1164
Treatment F	3.153	3.586	13.933	15.026	17.127	10.154
Treatment Prob(F)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means followed by same letter do not significantly differ (P=.05, LSD)

Trial Comments

GENERAL COMMENTS: Herbicides applied after bed shaping and just prior to laying plastic. Herbicides applied at 25 GPA with 11002 flat fan nozzles at 3 mph. Fumigants were applied with various rigs: metam sodium applied on top of soil and rototilled in top 4 inches; Telone 2 and Telone C35 shanked applied 12 to 14 inches deep with rototiller; Chloropicrin and methyl bromide applied with super bedder injecting fumigant 6 to 8 inches deep.

OBJECTIVE: Determine crop and nutsedge response to various methyl bromide alternatives.

RESULTS:

Crop Tolerance:

- 1) A significant fumigant by herbicide interaction was not noted.
- 2) Sulfentrazone, pooled over all fumigants, stunted tomato growth 12 percent at 3 WAT (weeks after applying treatments). By 6 WAT, no differences in tomato injury by herbicides was noted.
- 3) At 3 WAT, stunting from metam was greater than from any other fumigant option.

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4) By 6 WAT, stunting was greatest with metam sodium only or no fumigant. Stunting late in the season may have been a response to nematodes.

Weed Control:

Yellow nutsedge (fumigant):

1. Biologically, fumigant main effects were of the greatest significant value. Therefore, results are pooled over herbicide options.
2. Methyl bromide provided complete control of yellow nutsedge. Control was 33 to 34% more effective than the no fumigant option when pooled over the herbicide option.
3. Chloropicrin (282 lb) was the only fumigant option as effective as methyl bromide throughout the season.
4. Telone 2 followed by chloropicrin was 5 to 7% less effective than bromide and 27 to 29% more effective than the no fumigant option.
5. Telone C35 at 36 GPA was 14 to 18% less effective than bromide and 17 to 20% more effective than the no fumigant option.
6. Metam alone or in combination with Telone C35 were 20 to 29% less effective than methyl bromide and only 5 to 14% more effective than the no fumigant option.
7. Telone C35 at 18 GPA was 29% less effective than methyl bromide and no more effective than the no fumigant option.

Yellow nutsedge (herbicide)

1. Biologically, herbicide main effects were of the greatest significant value. Therefore, results are pooled over fumigant options.
2. All herbicide options improved control by at least 11% compared to the no herbicide option.
3. Generally, sulfentrazone, Sandea, and Dual plus Sandea provided similar control and control was slightly better than Dual applied alone.

Palmer amaranth (fumigant):

1. Pooled over herbicide options, all fumigants improved Palmer control by at least 14%.
2. Methyl bromide, chloropicrin options, and metam treatments were generally the most effective options.

Palmer amaranth (herbicides):

1. Pooled over fumigant options, the no herbicide treatment provided 77 to 79% control. All herbicides improved control.
2. Control was similar among all herbicide treatments.

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3-A (6)1

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + chloropicrin + metam-Na
[Insert Alternative]

Study: Fumigant/herbicide combinations
[Insert Study Title] in tomato

Section 1. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted _____
- 1b. Township caps _____
- 1c. Alternative not acceptable in consuming country _____
- 1d. Other (Please describe) X

Can be used in strawberry, tomato, pepper and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only

ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website?

Yes _____

No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s)

Culpepper

3. Publication and Date of Publication

Not published

4. Location of research study

Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

1,3-D + chloropicrin + metam-Na

6. Was crop yield measured in the study?

Yes _____

No X

7. Describe the effectiveness of the alternative in controlling pests in the study.

Not effective in controlling yellow nutsedge.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

We would expect similar results (lack of control) in North Carolina
across crops. Most growers do not have a rotovator to incorporate metam-Na
for best results.

Research Summary Table

Alternative: 1,3-D + Chloropicrin + Metam-NaStudy: Culpepper (unpublished)

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. al per area)	Pest 1: Percent Yellow Nutsedge Control						Pest 2						Yield (units/area)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	methyl bromide	375 lbs./acre	3 WAT	100	6 WAT	100									
36	1,3-D +														
	chloropicrin +	18 gal/acre													
	metam-Na	37 gal/acre	3 WAT	62.5	6 WAT	55									
46	nontreated		3 WAT	0	6 WAT	0									

Comments: WAT = weeks after treatment; yield was not determined in study.

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
1,3-D +	nutsedge	1,3-D	65%	123								
chloropirrin +		chloropirrin	35%	70	18	gal	\$ 13.10	\$ 75.00	80	100	1	\$ 380.80
metam-Na		metam-Na	4.26 HL	157.62	37	gal	\$ 4.00	\$ 15.00		100%	1	\$ 163.00
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 553.80

Comments: This does not include cost of hand weeding, which would be impossible and likely cost over \$2,000 per acre.

03-0041

Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

ID#

1,3-D + Chloropicrin + Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative* user.

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Tomato	grade, time, market	boxes (25 lb.)	*		*
				Total Revenue	*

Comments: * = could not be determined because yield was not determined in the study.

03-0041

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

1,3-D + Chloropicrin + Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item.	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	\$25.00			\$ 15.00	Tractor with tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

03-0041

N. C. State University

Trial ID:
Location:

Study Dir.:
Investigator: Stanley Culpepper

GENERAL TRIAL INFORMATION

Investigator: Culpepper/Langston Title: Extension
Affiliation: UGA

TRIAL LOCATION

City: Douglas Trial Status: completed
State/Prov.: GA Trial Reliability: fair
Country: USA Initiation Date: Mar-21-02

Conducted Under GLP (Y/N): N

Conducted Under GEP (Y/N): N

CROP AND WEED DESCRIPTION

Weed	Code	Common Name	Scientific Name
1.	CYPES	yellow nutsedge	
2.	AMAPA	Palmer amaranth	

Crop 1: tomat tomato

Variety: BHN 444

Planting Method: transplant

Rate: 1 20"

Depth: 2.5 "

Row Spacing: 6 ft

Seed Bed: bed/black plastic

Soil Moisture: drip

SITE AND DESIGN

Plot Width, Unit: 10 FT

Plot Length, Unit: 40 FT

Reps: 4

Site Type: on farm

Tillage Type: conventional

Study Design: FACTORIAL

CROP STAGE AT EACH APPLICATION

	A
Crop 1 Code, Stage:	tomat
Stage Scale:	PRE

WEED STAGE AT EACH APPLICATION

	A
Weed 1 Code, Stage:	CYPES
Stage Scale:	PRE
Weed 2 Code, Stage:	AMAPA
Stage Scale:	PRE

N. C. State University

Trial ID:

Study Dir.:

Location:

Investigator: Stanley Culpepper

Crop Code	tomato	tomato	CYPES	CYPES	AMAPA	AMAPA
Rating Data Type	injury	injury	control	control	control	control
Rating Unit	percent	percent	percent	percent	percent	percent
Rating Date	Apr-12-02	May-06-02	Apr-12-02	May-06-02	Apr-12-02	May-06-02
Weed Density, Unit	6 ydsq	7 ydsq	4 ydsq	4 ydsq	4 ydsq	4 ydsq
Trt Treatment	Rate	Grow				
No. Name	Rate Unit	Unit Stg				
1 MBR (375 lb/A) no herbicide	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
2 MBR (375 lb/A) Dual (1 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
3 MBR (375 lb/A) Sanda (0.024 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
4 MBR (375 lb/A) Sulfentrazone (0.2 lb ai)	7.5 d-h	0.0 g	100.0 a	100.0 a	97.8 a	100.0 a
5 MBR (375 lb/A) Dual (1 lb A/A) Sanda (0.24 lb A/A)	3.0 fgh	0.0 g	100.0 a	100.0 a	95.5 a-d	100.0 a
6 Pic (282 lb/A) no herbicide	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
7 Pic (282 lb/A) Dual (1 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
8 Pic (282 lb/A) Sanda (0.024 lb A/A)	0.0 h	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
9 Pic (282 lb/A) Sulfentrazone (0.2 lb ai)	10.0 d-g	0.0 g	100.0 a	100.0 a	97.0 ab	100.0 a
10 Pic (282 lb/A) Dual (1 lb A/A) Sanda (0.24 lb A/A)	6.3 d-h	0.0 g	100.0 a	100.0 a	98.0 a	100.0 a
11 T2 (10 G) fb Pic (150 lb) no herbicide	0.0 h	0.0 g	91.3 abc	93.8 a-e	93.8 a-d	95.0 abc
12 T2 (10 G) fb Pic (150 lb) Dual (1 lb A/A)	0.0 h	2.5 fg	95.8 ab	95.0 a-e	96.5 abc	100.0 a
13 T2 (10 G) fb Pic (150 lb) Sanda (0.024 lb A/A)	0.0 h	2.5 fg	96.5 ab	92.5 a-f	96.5 abc	90.0 a-d
14 T2 (10 G) fb Pic (150 lb) Sulfentrazone (0.2 lb ai)	10.0 d-g	2.5 fg	96.5 ab	93.3 a-e	96.5 abc	97.5 ab
15 T2 (10 G) fb Pic (150 lb) Dual (1 lb A/A) Sanda (0.24 lb A/A)	9.3 d-h	2.5 fg	96.5 ab	90.8 a-g	96.5 abc	100.0 a
16 Vapam (56 G) no herbicide	12.5 b-e	12.5 a-e	61.3 ijk	62.5 o-r	82.5 efg	95.0 abc
17 Vapam (56 G) Dual (1 lb A/A)	11.3 c-f	12.5 a-e	73.8 e-i	71.3 k-p	95.0 a-d	97.5 ab
18 Vapam (56 G) Sanda (0.024 lb A/A)	6.3 d-h	12.5 a-e	72.5 e-i	68.8 m-p	91.3 a-e	100.0 a
19 Vapam (56 G) Sulfentrazone (0.2 lb ai)	23.8 a	12.5 a-e	85.0 b-e	86.5 b-i	95.0 a-d	95.0 abc
20 Vapam (56 G) Dual (1 lb A/A) Sanda (0.24 lb A/A)	15.0 a-d	10.0 a-f	71.3 f-i	87.5 a-h	91.3 a-e	95.0 abc
21 Vapam (75 G) no herbicide	2.5 fgh	15.0 abc	62.5 ijk	63.8 n-r	82.5 efg	95.0 abc

N. C. State University

Crop Code Rating Data Type Rating Unit Rating Date Weed Density, Unit				tomato injury percent Apr-12-02	tomato injury percent May-06-02	CYPES control percent Apr-12-02 6 ydsq	CYPES control percent May-06-02 7 ydsq	AMAPA control percent Apr-12-02 4 ydsq	AMAPA control percent May-06-02 4 ydsq
Trt No.	Treatment Name	Rate	Grow Unit Stg						
22	Vapam (75 G) Dual (1 lb A/A)			6.3 d-h	15.0 abc	66.3 hij	71.3 k-p	93.8 a-d	100.0 a
23	Vapam (75 G) Sandeia (0.024 lb A/A)			8.8 d-h	13.8 a-d	90.0 a-d	98.8 ab	88.8 a-f	100.0 a
24	Vapam (75 G) Sulfentrazone (0.2 lb ai)			21.3 ab	16.3 ab	84.8 b-e	68.8 m-p	95.0 a-d	92.5 a-d
25	Vapam (75 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)			12.5 b-e	15.0 abc	88.8 a-d	97.5 abc	93.8 a-d	100.0 a
26	Telone C35 (18 G) no herbicide			0.0 h	7.5 b-g	52.5 k	52.5 r	76.3 gh	71.3 fg
27	Telone C35 (18 G) Dual (1 lb A/A)			0.0 h	7.5 b-g	67.5 g-j	73.8 i-o	91.0 a-e	96.3 abc
28	Telone C35 (18 G) Sandeia (0.024 lb A/A)			0.0 h	7.5 b-g	73.8 e-i	71.3 k-p	87.5 b-f	92.5 a-d
29	Telone C35 (18 G) Sulfentrazone (0.2 lb ai)			5.0 e-h	7.5 b-g	84.8 b-e	80.0 f-m	91.5 a-e	91.3 a-d
30	Telone C35 (18 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)			0.0 h	7.5 b-g	78.8 c-h	76.3 h-n	93.5 a-d	98.8 a
31	Telone C35 (36 G) no herbicide			0.0 h	3.8 efg	80.8 c-g	85.0 c-j	72.5 h	75.0 efg
32	Telone C35 (36 G) Dual (1 lb A/A)			0.0 h	3.8 efg	82.0 c-f	82.5 e-l	95.0 a-d	90.0 a-d
33	Telone C35 (36 G) Sandeia (0.024 lb A/A)			2.5 fgh	3.8 efg	77.0 d-h	86.3 b-i	90.0 a-f	83.8 c-f
34	Telone C35 (36 G) Sulfentrazone (0.2 lb ai)			9.3 d-h	3.8 efg	89.8 a-d	85.0 c-j	86.3 def	85.0 b-e
35	Telone C35 (36 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)			8.8 d-h	3.8 efg	89.8 a-d	92.5 a-f	87.5 b-f	92.5 a-d
36	Telone C35 (18 G) Vapam (37 G) no herbicide			2.5 fgh	6.8 c-g	62.5 ijk	55.0 qr	81.3 fgh	65.0 g
37	Telone C35 (18 G) Vapam (37 G) Dual (1 lb A/A)			0.0 h	6.8 c-g	71.3 f-i	67.5 m-q	92.5 a-d	87.5 a-e
38	Telone C35 (18 G) Vapam (37 G) Sandeia (0.024 lb A/A)			2.5 fgh	6.8 c-g	74.5 e-i	78.8 g-m	93.8 a-d	95.0 abc
39	Telone C35 (18 G) Vapam (37 G) Sulfentrazone (0.2 lb ai)			1.3 gh	6.8 c-g	77.5 d-h	71.3 k-p	95.0 a-d	98.8 a
40	Telone C35 (18 G) Vapam (37 G) Dual (1 lb A/A) Sandeia (0.24 lb A/A)			3.8 e-h	6.8 c-g	90.0 a-d	96.3 a-d	95.0 a-d	97.5 ab
41	Telone C35 (18 G) Vapam (56 G) no herbicide			2.5 fgh	5.5 d-g	67.5 g-j	72.5 j-o	91.3 a-e	93.8 abc

N. C. State University

Crop Code	tomato	tomato	CYPES	CYPES	AMAPA	AMAPA
Rating Data Type	injury	injury	control	control	control	control
Rating Unit	percent	percent	percent	percent	percent	percent
Rating Date	Apr-12-02	May-06-02	Apr-12-02	May-06-02	Apr-12-02	May-06-02
Weed Density, Unit	6 ydsq	7 ydsq	4 ydsq	4 ydsq	4 ydsq	4 ydsq
Trt Treatment	Rate	Grow				
No: Name	Rate	Unit	Stg			
42 Telone C35 (18 G) Vapam (56 G) Dual (1 lb A/A)	2.5 fgh	5.5 d-g	56.3 jk	58.8 pqr	86.3 def	93.8 abc
43 Telone C35 (18 G) Vapam (56 G) Sanda (0.024 lb A/A)	3.8 e-h	5.5 d-g	81.5 c-f	90.0 a-g	95.0 a-d	88.8 a-d
44 Telone C35 (18 G) Vapam (56 G) Sulfentrazone (0.2 lb ai)	20.0 abc	5.5 d-g	88.8 a-d	87.0 a-h	92.5 a-d	88.8 a-d
45 Telone C35 (18 G) Vapam (56 G) Dual (1 lb A/A) Sanda (0.24 lb A/A)	3.8 e-h	5.5 d-g	62.5 ijk	65.0 n-r	95.0 a-d	91.3 a-d
46 non-treated no herbicide	0.0 h	18.8 a	0.0 l	0.0 s	0.0 i	0.0 h
47 non-treated Dual (1 lb A/A)	7.5 d-h	18.8 a	82.0 c-f	87.5 a-h	93.8 a-d	95.0 abc
48 non-treated Sanda (0.024 lb A/A)	5.0 e-h	18.8 a	85.0 b-e	90.0 a-g	88.0 b-f	95.0 abc
49 non-treated Sulfentrazone (0.2 lb ai)	11.3 c-f	18.8 a	82.0 c-f	70.0 l-p	82.3 efg	80.0 def
50 non-treated Dual (1 lb A/A) Sanda (0.24 lb A/A)	5.0 e-h	18.8 a	83.8 b-f	83.8 d-k	87.3 c-f	90.0 a-d
LSD (P=.05)	9.41	9.03	13.37	13.14	9.62	13.48
Standard Deviation	6.72	6.45	9.55	9.38	6.87	9.63
CV	127.89	90.54	11.72	11.44	7.63	10.49
Replicate F	1.817	5.057	3.672	2.102	3.232	2.001
Replicate Prob(F)	0.1467	0.0023	0.0137	0.1025	0.0242	0.1164
Treatment F	3.153	3.586	13.933	15.026	17.127	10.154
Treatment Prob(F)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means followed by same letter do not significantly differ (P=.05, LSD)

Trial Comments

GENERAL COMMENTS: Herbicides applied after bed shaping and just prior to laying plastic. Herbicides applied at 25 GPA with 11002 flat fan nozzles at 3 mph. Fumigants were applied with various rigs: metam sodium applied on top of soil and rototilled in top 4 inches; Telone 2 and Telone C35 shanked applied 12 to 14 inches deep with rototiller; Chloropicrin and methyl bromide applied with super bedder injecting fumigant 6 to 8 inches deep.

OBJECTIVE: Determine crop and nutsedge response to various methyl bromide alternatives.

RESULTS:

Crop Tolerance:

- 1) A significant fumigant by herbicide interaction was not noted.
- 2) Sulfentrazone, pooled over all fumigants, stunted tomato growth 12 percent at 3 WAT (weeks after applying treatments). By 6 WAT, no differences in tomato injury by herbicides was noted.
- 3) At 3 WAT, stunting from metam was greater than from any other fumigant option.

N. C. State University

4) By 6 WAT, stunting was greatest with metam sodium only or no fumigant. Stunting late in the season may have been a response to nematodes.

Weed Control:

Yellow nutsedge (fumigant):

1. Biologically, fumigant main effects were of the greatest significant value. Therefore, results are pooled over herbicide options.
2. Methyl bromide provided complete control of yellow nutsedge. Control was 33 to 34% more effective than the no fumigant option when pooled over the herbicide option.
3. Chloropicrin (282 lb) was the only fumigant option as effective as methyl bromide throughout the season.
4. Telone 2 followed by chloropicrin was 5 to 7% less effective than bromide and 27 to 29% more effective than the no fumigant option.
5. Telone C35 at 36 GPA was 14 to 18% less effective than bromide and 17 to 20% more effective than the no fumigant option.
6. Metam alone or in combination with Telone C35 were 20 to 29% less effective than methyl bromide and only 5 to 14% more effective than the no fumigant option.
7. Telone C35 at 18 GPA was 29% less effective than methyl bromide and no more effective than the no fumigant option.

Yellow nutsedge (herbicide)

1. Biologically, herbicide main effects were of the greatest significant value. Therefore, results are pooled over fumigant options.
2. All herbicide options improved control by at least 11% compared to the no herbicide option.
3. Generally, sulfentrazone, Sandea, and Dual plus Sandea provided similar control and control was slightly better than Dual applied alone.

Palmer amaranth (fumigant):

1. Pooled over herbicide options, all fumigants improved Palmer control by at least 14%.
2. Methyl bromide, chloropicrin options, and metam treatments were generally the most effective options.

Palmer amaranth (herbicides):

1. Pooled over fumigant options, the no herbicide treatment provided 77 to 79% control. All herbicides improved control.
2. Control was similar among all herbicide treatments.

For EPA Use Only
ID#**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: 1,3-D + chloropicrin

[Insert Alternative]

Study: Pepper and nutsedge to fumigant/

[Insert Study Title] herbicide combinati

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted	<u>X</u>
1b. Township caps	<u> </u>
1c. Alternative not acceptable in consuming country	<u> </u>
1d. Other (Please describe)	<u> </u>

This alternative can be used in tomato, pepper, strawberry and
cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only

ID# _____

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**Section II. Existing Research Studies on Alternatives to Methyl Bromide**1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Rucker, Langston and Culpepper3. Publication and Date of Publication Not published4. Location of research study Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

1,3-D + chloropicrin6. Was crop yield measured in the study? Yes _____ No X

7. Describe the effectiveness of the alternative in controlling pests in the study.

The alternative gave similar control to methyl bromide, however there were escapes of yellow nutsedge not controlled and purple nutsedge control was approximately 10% less controlled by this alternative.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

I believe that this alternative would not give consistent nutsedge control in North Carolina because based on this work and others. The approximate 10% increased control with methyl bromide is very important especially in reinfestation and continued competition with the crop. Similar results would be likely in pepper, tomato, strawberry and cucurbit crops.

Research Summary Table

Alternative: 1,3-D + ChloropicrinStudy: Rucker, Langston and Culpepper (unpublished)

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col. F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. a/ per area)	Pest 1: Yellow Nutsedge (no. per ft ²)						Pest 2: Purple Nutsedge Control (%)						Yield (units/area)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		8 WAT	13					8 WAT	56					
8	methyl bromide	300 lbs./acre	8 WAT	0					8 WAT	83					
15	1,3-D +														
	chloropicrin	20 gal/acre	8 WAT	2.3					8 WAT	75					

Comments: WAT = weeks after treatment; yield was not determined in study.

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If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by th user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
1,3-D +	nursedge	1,3-D	65%		20	gal	\$ 13.10	\$ 75.00	80	100	1	\$ 417.00
chloropicrin		chloropicrin	35%									
Non-Chemical Pest Control	Target Pests	Description										Cost/area
											Total	\$ 417.00

Comments: This does not include cost of hand weeding, which would be impossible and would likely cost over \$2,000 per acre.

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Worksheet 3-C. Alternatives - Crop/Commodity Yield and Gross Revenue for Alternati

ID#

1,3-D + Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a <i>representative</i> user.					
The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.					
Col. A: Crop/Commodity	Enter all crops/commodities that can be grown/treated during the same interval of time comprising a methyl bromide fumigation cycle. Please discuss changes in crop cycles resulting from alternative use in the comments. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.				
Col. B: Price Factors	Enter in Col. B any factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g., fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of alternatives affects these price factors.				
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for your crop/commodity.				
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor identified.				
Col. E: Price	Enter the average 2001 prices received by the users for that crop/commodity and price factor.				
Col. F: Gross Revenue	In the electronic version, revenue is automatically calculated below using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the				
Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.					
A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Pepper	grade, time, market	boxes (25 lb.)	*	\$ 8.25	*
				Total Revenue	*
Comments: * = could not be determined because yield was not determined in the study.					

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Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

1,3-D + Chloropicrin

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Total Custom per Area			User Total per area		

Comments: No change

N. C. State University

Pepper and nutsedge response to fumigant/herbicide combinations.

Trial ID: Fum1-01 Study Dir.: Rucker/Langston/Culpepper
Location: Tift County Investigator: Stanley Culpepper

GENERAL TRIAL INFORMATION

Study Director: Rucker/Langston/Culpepper Title: Extension
Affiliation: UGA
Investigator: Stanley Culpepper Title: Ext. Weed Science
Affiliation: UGA
Trial Status: completed Initiation Date: Mar-09-01
City: Tifton
Conducted Under GLP (Y/N): N Conducted Under GEP (Y/N): N

CROP AND PEST DESCRIPTION

Weed 1.CYPES yellow nutsedge

Crop 1:pepp pepper Variety: working on this Planting Date: Apr-05-01
Planting Method: transplants Rate: 1 row foot
Seed Bed: plasticulture

Plot Width, Unit: 6 FT Plot Length, Unit: 13 FT Reps: 4
Site Type: Lewis Taylor farm
Tillage Type: conventional Study Design: SPLIT-PLOT

APPLICATION DESCRIPTION

	A	B	C	D	E	F
Application Date:	Mar-09-01					
Time of Day:	all day					
Application Method:	broadcast					
Application Timing:	PRE/PPI					
Applic. Placement:	under pla					
Air Temp., Unit:	75 F					
% Relative Humidity:	95					
Wind Velocity, Unit:	2 mph					
Dew Presence (Y/N):	n					
Soil Temp., Unit:	77 F					
Soil Moisture:	fair					
% Cloud Cover:	25					

CROP STAGE AT EACH APPLICATION

	A	B	C	D	E	F
Crop 1 pepp Stage:	prior					
Stage Scale:	to transp					

WEED STAGE AT EACH APPLICATION

	A	B	C	D	E	F
Weed 1 CYPES Stage:	PRE					

N. C. State University**APPLICATION EQUIPMENT**

A B C D E F

Appl. Equipment: see
Operating Pressure: comments

N. C. State University

Pepper and nutsedge response to fumigant/herbicide combinations.

Trial ID: Fum1-01
Location: Tift County

Study Dir.: Rucker/Langston/Culpepper
Investigator: Stanley Culpepper

Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt No.	Treatment Name	Rate Unit	Grow Stg			
1	None None			0.0 s	13.0 a	56.3 l
2	None Dual Magnum	1 PT/A	PRE	0.0 s	4.0 b-i	73.5 h-k
3	None Sandeia	0.024 LB A/A	PRE	0.0 s	4.8 b-g	72.0 ijk
4	None Sulfentrazone	0.25 LB A/A	PRE	38.8 efg	4.5 b-h	90.0 a-f
5	None Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	2.5 qrs	2.5 b-i	89.8 a-f
6	None Treflan	1 PT/A	PPI	5.0 o-s	6.0 bc	75.8 f-k
7	None Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	7.5 m-s	3.5 b-i	85.0 a-i
8	MB 300 None			0.0 s	0.0 i	82.5 a-k
9	MB 300 Dual Magnum	1 PT/A	PRE	0.0 s	0.0 i	84.8 a-i
10	MB 300 Sandeia	0.024 LB A/A	PRE	8.8 m-s	0.5 hi	91.0 a-e
11	MB 300 Sulfentrazone	0.25 LB A/A	PRE	37.5 fgh	0.0 i	92.5 abc
12	MB 300 Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	13.8 l-r	0.0 i	96.0 a
13	MB 300 Treflan	1 PT/A	PPI	1.3 rs	0.0 i	83.8 a-j
14	MB 300 Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	47.5 c-f	0.0 i	85.8 a-i
15	C35-20GPA None			0.0 s	2.3 c-i	75.0 f-k
16	C35-20GPA Dual Magnum	1 PT/A	PRE	2.5 qrs	1.3 f-i	91.3 a-e
17	C35-20GPA Sandeia	0.024 LB A/A	PRE	5.5 o-s	1.5 e-i	90.0 a-f
18	C35-20GPA Sulfentrazone	0.25 LB A/A	PRE	11.3 m-s	0.3 i	92.5 abc
19	C35-20GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	13.8 l-r	1.3 f-i	92.5 abc
20	C35-20GPA Treflan	1 PT/A	PPI	3.8 p-s	1.8 d-i	83.8 a-j

N. C. State University

Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt No.	Treatment Name	Rate	Unit Grow Stg			
21	C35-20GPA Sandeia Treflan	0.024	LB A/A PPI 1 PT/A PPI	57.5 abc	0.8 ghi	83.8 a-j
22	C35-27.5GPA None			0.0 s	2.0 c-i	78.8 b-k
23	C35-27.5GPA Dual Magnum	1	PT/A PRE	0.0 s	0.0 i	92.5 abc
24	C35-27.5GPA Sandeia	0.024	LB A/A PRE	8.8 m-s	0.3 i	79.5 b-k
25	C35-27.5GPA Sulfentrazone	0.25	LB A/A PRE	10.0 m-s	1.0 f-i	92.5 abc
26	C35-27.5GPA Dual Magnum Sandeia	1 0.024	PT/A PRE LB A/A PRE	17.5 k-o	0.5 hi	87.5 a-h
27	C35-27.5GPA Treflan	1	PT/A PPI	2.5 qrs	0.8 ghi	77.5 c-k
28	C35-27.5GPA Sandeia Treflan	0.024	LB A/A PPI 1 PT/A PPI	65.0 a	0.0 i	90.0 a-f
29	C35-35GPA None			0.0 s	4.0 b-i	77.3 d-k
30	C35-35GPA Dual Magnum	1	PT/A PRE	0.0 s	0.3 i	93.5 ab
31	C35-35GPA Sandeia	0.024	LB A/A PRE	2.5 qrs	1.3 f-i	95.0 a
32	C35-35GPA Sulfentrazone	0.25	LB A/A PRE	13.8 l-r	0.0 i	86.3 a-i
33	C35-35GPA Dual Magnum Sandeia	1 0.024	PT/A PRE LB A/A PRE	17.5 k-o	0.0 i	93.8 ab
34	C35-35GPA Treflan	1	PT/A PPI	0.0 s	2.8 b-i	78.8 b-k
35	C35-35GPA Sandeia Treflan	0.024	LB A/A PPI 1 PT/A PPI	61.3 ab	0.0 i	81.0 a-k
36	MS-37.5GPA None			0.0 s	4.8 b-g	75.0 f-k
37	MS-37.5GPA Dual Magnum	1	PT/A PRE	2.5 qrs	3.0 b-i	85.0 a-i
38	MS-37.5GPA Sandeia	0.024	LB A/A PRE	0.0 s	5.5 b-e	76.3 e-k
39	MS-37.5GPA Sulfentrazone	0.25	LB A/A PRE	33.8 gh	2.3 c-i	81.0 a-k
40	MS-37.5GPA Dual Magnum Sandeia	1 0.024	PT/A PRE LB A/A PRE	0.0 s	2.5 b-i	78.3 c-k
41	MS-37.5GPA Treflan	1	PT/A PPI	3.0 qrs	5.0 b-f	73.8 g-k
42	MS-37.5GPA Sandeia Treflan	0.024	LB A/A PPI 1 PT/A PPI	12.3 m-s	1.3 f-i	78.8 b-k

N. C. State University

Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01	
Trt No.	Treatment Name	Rate Rate	Unit Unit	Grow Stg			
43	MS-56.3GPA None				0.0 s	6.5 b	73.8 g-k
44	MS-56.3GPA Dual Magnum	1 PT/A	PRE		0.0 s	1.5 e-i	92.5 abc
45	MS-56.3GPA Sandeia	0.024 LB A/A	PRE		0.0 s	5.8 bcd	78.8 b-k
46	MS-56.3GPA Sulfentrazone	0.25 LB A/A	PRE		35.0 fgh	2.0 c-i	90.0 a-f
47	MS-56.3GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE		0.0 s	1.3 f-i	91.5 a-d
48	MS-56.3GPA Treflan	1 PT/A	PPI		0.0 s	2.8 b-i	76.3 e-k
49	MS-56.3GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI		16.3 l-p	1.0 f-i	88.8 a-g
50	MS-75GPA None				0.0 s	5.0 b-f	78.3 c-k
51	MS-75GPA Dual Magnum	1 PT/A	PRE		0.0 s	0.8 ghi	82.5 a-k
52	MS-75GPA Sandeia	0.024 LB A/A	PRE		2.5 qrs	2.0 c-i	89.5 a-f
53	MS-75GPA Sulfentrazone	0.25 LB A/A	PRE		31.3 g-j	1.3 f-i	91.0 a-e
54	MS-75GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE		2.0 rs	1.3 f-i	88.5 a-h
55	MS-75GPA Treflan	1 PT/A	PPI		0.0 s	5.5 b-e	69.5 jkl
56	MS-75GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI		20.0 i-m	0.5 hi	79.3 b-k
57	C35-20GPA+MS-37.5GPA None				0.0 s	0.3 i	75.0 f-k
58	C35-20GPA+MS-37.5GPA Dual Magnum	1 PT/A	PRE		5.0 o-s	0.0 i	94.8 a
59	C35-20GPA+MS-37.5GPA Sandeia	0.024 LB A/A	PRE		9.3 m-s	0.0 i	94.8 a
60	C35-20GPA+MS-37.5GPA Sulfentrazone	0.25 LB A/A	PRE		13.8 l-r	0.0 i	92.5 abc
61	C35-20GPA+MS-37.5GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE		15.0 l-q	0.0 i	92.5 abc
62	C35-20GPA+MS-37.5GPA Treflan	1 PT/A	PPI		7.5 m-s	1.0 f-i	67.5 kl
63	C35-20GPA+MS-37.5GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI		51.3 b-e	0.0 i	91.0 a-e
64	C35-20GPA+MS-56.3GPA None				0.0 s	0.0 i	82.5 a-k

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Sep-04-02 (Fum1-01)

AOV Means Table Page 4 of 6

N. C. State University

Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt No.	Treatment Name	Rate	Unit	Grow Stg		
65	C35-20GPA+MS-56.3GPA Dual Magnum	1 PT/A	PRE	3.8 p-s	0.0 i	91.0 a-e
66	C35-20GPA+MS-56.3GPA Sandeia	0.024 LB A/A	PRE	6.3 n-s	1.0 f-i	79.5 b-k
67	C35-20GPA+MS-56.3GPA Sulfentrazone	0.25 LB A/A	PRE	11.3 m-s	0.3 i	93.5 ab
68	C35-20GPA+MS-56.3GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	18.8 j-n	0.0 i	93.5 ab
69	C35-20GPA+MS-56.3GPA Treflan	1 PT/A	PPI	2.5 qrs	1.8 d-i	75.0 f-k
70	C35-20GPA+MS-56.3GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	32.5 ghi	1.0 f-i	77.5 c-k
71	C35-10GPA+MS25GPA None			0.0 s	0.3 i	86.3 a-i
72	C35-10GPA+MS25GPA Dual Magnum	1 PT/A	PRE	0.0 s	1.5 e-i	86.0 a-i
73	C35-10GPA+MS25GPA Sandeia	0.024 LB A/A	PRE	8.8 m-s	1.0 f-i	77.5 c-k
74	C35-10GPA+MS25GPA Sulfentrazone	0.25 LB A/A	PRE	10.8 m-s	0.8 ghi	77.5 c-k
75	C35-10GPA+MS25GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	25.5 h-i	0.0 i	91.3 a-e
76	C35-10GPA+MS25GPA Treflan	1 PT/A	PPI	0.0 s	1.0 f-i	77.5 c-k
77	C35-10GPA+MS25GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	42.5 d-g	0.8 ghi	78.8 b-k
78	Chloropicrin 125 lb Metam sodium 56.3 GP None			0.0 s	0.0 i	92.0 a-d
79	Chloropicrin 125 lb Metam sodium 56.3 GP Dual Magnum	1 PT/A	PRE	0.0 s	0.0 i	92.5 abc
80	Chloropicrin 125 lb Metam sodium 56.3 GP Sandeia	0.024 LB A/A	PRE	10.0 m-s	0.0 i	90.0 a-f
81	Chloropicrin 125 lb Metam sodium 56.3 GP Sulfentrazone	0.25 LB A/A	PRE	30.0 g-k	0.0 i	93.8 ab
82	Chloropicrin 125 lb Metam sodium 56.3 GP Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	25.0 h-i	0.0 i	93.8 ab
83	Chloropicrin 125 lb Metam sodium 56.3 GP Treflan	1 PT/A	PPI	0.0 s	0.0 i	87.5 a-h

N. C. State University

Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt No.	Treatment Name	Rate	Unit	Grow Stg		
84	Chloropicrin 125 lb Metam sodium 56.3 GP Sanda Treflan	0.024	LB A/A 1 PT/A	PPI PPI	55.0 a-d 0.0 i	93.8 ab
LSD (P=.05)				12.56	4.05	15.11
Standard Deviation				9.06	2.92	10.90
CV				76.28	185.74	12.88
Replicate F				2.024	0.699	4.148
Replicate Prob(F)				0.1115	0.5535	0.0070
Treatment F				13.241	2.174	2.147
Treatment Prob(F)				0.0001	0.0001	0.0001

Means followed by same letter do not significantly differ (P=.05, LSD)

Mean separations are based on the complete error term.

Trial Comments

OBJECTIVE: To compare 12 fumigant by 7 herbicide options for control of nutsedge and pepper tolerance.

Crop Tolerance:

- 1) A significant fumigant by herbicide interaction was noted for crop tolerance.
- 2) Pepper was tolerant to Dual applied at 1 pt/A under plastic regardless of fumigant.
- 3) Pepper showed minor and insignificant stunting from Sandea applied PRE at 0.024 lb A/A regardless of fumigant. There was a trend for less injury when applied in combination with metam sodium as compared to any other fumigant option.
- 4) Pepper was severely injured (30 to 39%) by sulfentrazone applied PRE under plastic when bromide, metam sodium, chloropicrin plus metam sodium or no fumigant were the fumigant option. However, when sulfentrazone was applied with any fumigant combination containing at least 20 gallons of Telone C-35 injury was less than 12%.
- 5) Dual plus Sandea injured pepper 2.5% when no fumigant was applied. Applying bromide, Telone C35 alone or mixed with metam sodium, or Chloropicrin injured pepper 14 to 25%. In contrast no injury was noted when Dual plus Sandea was applied with metam sodium (same trend as Sandea applied alone).
- 6) Treflan injured pepper less than 8%, regardless of fumigant.
- 7) Treflan plus Sandea injured Pepper 8% when no fumigant was applied. Applying metam sodium in combination with Treflan + Sandea did not increase injury; however, Telone C-35, Bromide, and Chloropicrin plus metam sodium increased injury by at least 25% with injury ranging from 33 to 65%.

Early Season Yellow Nutsedge Control:

- 1) Significant main effects of fumigant and herbicide were noted for nutsedge control.
- 2) All fumigant options reduced nutsedge emergence by at least 40% compared to no fumigant under the plastic.
- 3) The least effective fumigant options were metam sodium at 37.5, 56.3, and 75 GPA.
- 4) Trends were apparent for Bromide, Chloropicrin plus metam sodium, and Telone C35 plus metam sodium combinations to be the most effective options.
- 5) Treflan did not significantly reduce nutsedge populations.
- 6) Sulfentrazone, Dual Magnum, and Dual Magnum plus Sandea PRE as well as Sandea plus Treflan incorporated reduced nutsedge population similarly and were generally more effective than Sandea applied PRE under plastic.

Late Season Yellow Nutsedge Control:

- 1) Significant Main effects of fumigant and herbicide were noted.
- 2) The plastic alone controlled yellow nutsedge 56%. Pooled over fumigant option, nutsedge was controlled 78% when no herbicide was applied.
- 3) Metam sodium, regardless of rate, did not improve yellow nutsedge control compared to the no fumigant option.

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- 4) Chloropicrin plus metam sodium, Bromide, Telone C35, and Telone C35 plus Metam combinations controlled nutsedge similarly.
- 5) There was a trend throughout the data for the Chloropicrin plus metam sodium combination to be the most effective fumigant option.
- 6) Treflan had no impact on nutsedge control.
- 7) Dual Magnum plus Sandea, Sulfentrazone, and Dual Magnum alone controlled nutsedge similarly and tended to be the most effective herbicide options.

CONCLUSIONS:

Injury in this trial is very consistent but extremely confusing.

Metam sodium was the least effective fumigant option.

Dual, Dual + Sandea, and Sandea may all have a potential use for peppers under plastic.

We are screwed if we have to test all of the potentially new herbicides with the mass of fumigant options being implemented by our growers; however, this data suggest that may be necessary.

GENERAL COMMENTS

Mar-09-01:

- 1.) Took two days to put all treatments out.
 - 2.) Applied Telone with tilrovator followed by bed press.
 - 3.) Metam sprayed with boom and incorporated 3 to 5 inches with tilrovator in a single pass.
 - 4.) Co-applications of Telone C35 and metam were done with a single piece of equipment.
 - 5.) Bromide and Chloropicrin applied with superbetter.
 - 6.) PPI herbicide treatments were applied and incorporated with tilrovator. PRE herbicides were applied immediately after forming bed and just prior to laying plastic in a single operation. Herbicides applied at 20 gallons per acre.
- Jul-09-01: Ratings were compared to a true non-treated control (ie no plastic)

A LATE FALL RATING IN THE NEXT CROP WILL BE TAKEN FOR LONG TERM IMPACT.

For EPA Use Only
ID#**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as needed.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: Metam Na

[Insert Alternative]

Study: Pepper and nutsedge response to fumigant/herbicide combinations

[Insert Study Title]

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

1a. Full use permitted _____

1b. Township caps _____

1c. Alternative not acceptable in consuming country _____

1d. Other (Please describe) _____

This alternative can be used in tomato, pepper, strawberry and cucurbit crops.

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

For EPA Use Only
ID# _____**Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide****Section II. Existing Research Studies on Alternatives to Methyl Bromide**1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

2. Author(s) or researcher(s) Rucker, Langston and Culpepper3. Publication and Date of Publication Not published4. Location of research study Georgia

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

6. Was crop yield measured in the study? Yes _____ No X

7. Describe the effectiveness of the alternative in controlling pests in the study.

The alternative gave similar control in some respects to methyl bromide,
however, there were escapes of yellow nutsedge and purple nutsedge.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

I do not believe that this alternative would give consistent nutsedge
control since yellow nutsedge escaped control. I would expect similar
results in North Carolina as Georgia. Similar results would be likely in
pepper, tomato, strawberry and cucurbit crops. Most growers do not have
access to a tractor mounted tiller.

Research Summary Table

Alternative: Metam-NaStudy: Rucker, Langston and Culpepper (unpublished)

Provide one summary table for each study being described.

Provide a summary table of research information that will allow us compare the impact of methyl bromide and the alternative regimen on such things as pest control, yield or quality of the commodity being treated, or protected. Ideally, a research study should directly compare methyl bromide and the alternative regimen.

Col. A: Treatment Number	List the treatment number from the research study you are citing.
Col. B: Treatment	List what type of pest control method was used.
Col. C: Rate	Enter the pounds or gallons of a chemical used, days of solarization, etc.
Col. D, F, H, J, L, N: Interval	Enter the interval after treatment that the rating was taken. Enter the interval (days, weeks or months) in the column heading or in the comments section. In the comments describe the rating scale (e.g. 0 to 100 where 100 is complete control).
Cols. E, G, I, K, M, O: Rating for Interval:	Use these columns to describe the level of control provided for a specific pest and the time interval at which the rating was taken. For example, a study for nematode control may have looked at nematode population in the soil pre-treatment, 3 weeks after treatment, and 6 weeks after treatment. In this example, type over the words "Rating Interval 1" with "pre-treatment", type over "Rating Interval 2" with "3 weeks", and type over "Rating Interval 3" with "6 weeks." If you are completing the printed version, please define Rating Interval in the comments below.
Control of Pests 1 and 2 (Cols. D - I and Cols. J - O):	For the target pest(s) in the study list the pest or pest species being rated in the column header or the comments section. For example, a study for nematode control in tomatoes may have looked at sting nematode and stunt nematode. Enter sting nematode for pest 1 in the Col F header below and stunt nematode for pest 2 in the Col. L header below. In the comments section describe the rating system used (0 to 100 scale where 0 is no control, number of nematodes per gram of soil, number of colony forming units per gram of soil, etc.).
Col. J: Yield	Enter the marketable yield of the crop or commodity and specify the units (lbs./acre, tons) in the column header or comments section.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Treatment Number	Treatment	Rate (lbs. or gals. at per area)	Pest 1: Yellow Nutsedge (no. per 78 ft ²)						Pest 2: Purple Nutsedge Control (%)						Yield (units/area)
			Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	Interval 1	Interval 1	Interval 2	Rating for Interval 2	Interval 3	Rating for Interval 3	
1	nontreated		8 WAT	13						56					
8	methyl bromide	300 lbs./acre	8 WAT	0						83					
36	metam-Na	37.5 gal/acre	8 WAT	4.8						75					

Comments: WAT = weeks after treatment; yield was not determined in study.

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crop grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Application per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
metam-Na	nutsedge	metam-Na	4.26 HL		37.5	gal	\$ 4.00	\$ 90.00	80	100	1	\$ 320.00
Non-Chemical Pest Control	Target Pests	Description										Cost/area
Total												\$ 320.00

Comments: This does not include cost of hand weeding, which would be impossible for nutsedge control and would likely cost over \$2,000 per acre.

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ID#

Revenue (per area)	
1.25	

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments: * = could not be determined because yield was not determined in the study.

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

ID#

Metam-Na

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
Tilling	\$25.00			\$ 15.00	Tractor with tillage
Total Custom per Area	\$ 25.00		User Total per area	\$ 15.00	

Comments:

03-0041

N. C. State University

Pepper and nutsedge response to fumigant/herbicide combinations.

Trial ID: Fum1-01	Study Dir.: Rucker/Langston/Culpepper
Location: Tift County	Investigator: Stanley Culpepper

GENERAL TRIAL INFORMATION

Study Director: Rucker/Langston/Culpepper	Title: Extension
Affiliation: UGA	
Investigator: Stanley Culpepper	Title: Ext. Weed Science
Affiliation: UGA	

Trial Status: completed	Initiation Date: Mar-09-01
City: Tifton	
Conducted Under GLP (Y/N): N	Conducted Under GEP (Y/N): N

CROP AND PEST DESCRIPTION

Weed 1.CYPES yellow nutsedge

Crop 1:pepp pepper	Variety: working on this	Planting Date: Apr-05-01
Planting Method: transplants	Rate: 1	row foot
		Seed Bed: plasticulture

Plot Width, Unit: 6	FT	Plot Length, Unit: 13	FT	Reps: 4
Site Type: Lewis Taylor farm				
Tillage Type: conventional		Study Design: SPLIT-PLOT		

APPLICATION DESCRIPTION

	A	B	C	D	E	F
Application Date:	Mar-09-01					
Time of Day:	all day					
Application Method:	broadcast					
Application Timing:	PRE/PPI					
Applic. Placement:	under pla					
Air Temp., Unit:	75	F				
% Relative Humidity:	95					
Wind Velocity, Unit:	2	mph				
Dew Presence (Y/N):	n					
Soil Temp., Unit:	77	F				
Soil Moisture:	fair					
% Cloud Cover:	25					

CROP STAGE AT EACH APPLICATION

	A	B	C	D	E	F
Crop 1 pepp Stage:	prior					
Stage Scale:	to transp					

WEED STAGE AT EACH APPLICATION

	A	B	C	D	E	F
Weed 1 CYPES Stage:	PRE					

N. C. State University**APPLICATION EQUIPMENT**

	A	B	C	D	E	F
Appl. Equipment:	see					
Operating Pressure:	comments					

N. C. State University

Pepper and nutsedge response to fumigant/herbicide combinations.

Trial ID: Fum1-01
Location: Tift County

Study Dir.: Rucker/Langston/Culpepper
Investigator: Stanley Culpepper

Weed Code	Crop Code	Rating Data Type	Rating Unit	Rating Date	pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt No.	Treatment Name	Rate	Unit	Grow Stg			
1	None None				0.0 s	13.0 a	56.3 l
2	None Dual Magnum	1 PT/A	PRE		0.0 s	4.0 b-i	73.5 h-k
3	None Sandea	0.024 LB A/A	PRE		0.0 s	4.8 b-g	72.0 ijk
4	None Sulfentrazone	0.25 LB A/A	PRE		38.8 efg	4.5 b-h	90.0 a-f
5	None Dual Magnum Sandea	1 PT/A 0.024 LB A/A	PRE PRE		2.5 qrs	2.5 b-i	89.8 a-f
6	None Treflan	1 PT/A	PPI		5.0 o-s	6.0 bc	75.8 f-k
7	None Sandea Treflan	0.024 LB A/A 1 PT/A	PPI PPI		7.5 m-s	3.5 b-i	85.0 a-i
8	MB 300 None				0.0 s	0.0 i	82.5 a-k
9	MB 300 Dual Magnum	1 PT/A	PRE		0.0 s	0.0 i	84.8 a-i
10	MB 300 Sandea	0.024 LB A/A	PRE		8.8 m-s	0.5 hi	91.0 a-e
11	MB 300 Sulfentrazone	0.25 LB A/A	PRE		37.5 fgh	0.0 i	92.5 abc
12	MB 300 Dual Magnum Sandea	1 PT/A 0.024 LB A/A	PRE PRE		13.8 l-r	0.0 i	96.0 a
13	MB 300 Treflan	1 PT/A	PPI		1.3 rs	0.0 i	83.8 a-j
14	MB 300 Sandea Treflan	0.024 LB A/A 1 PT/A	PPI PPI		47.5 c-f	0.0 i	85.8 a-i
15	C35-20GPA None				0.0 s	2.3 c-i	75.0 f-k
16	C35-20GPA Dual Magnum	1 PT/A	PRE		2.5 qrs	1.3 f-i	91.3 a-e
17	C35-20GPA Sandea	0.024 LB A/A	PRE		5.5 o-s	1.5 e-i	90.0 a-f
18	C35-20GPA Sulfentrazone	0.25 LB A/A	PRE		11.3 m-s	0.3 i	92.5 abc
19	C35-20GPA Dual Magnum Sandea	1 PT/A 0.024 LB A/A	PRE PRE		13.8 l-r	1.3 f-i	92.5 abc
20	C35-20GPA Treflan	1 PT/A	PPI		3.8 p-s	1.8 d-i	83.8 a-j

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Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt. Treatment No. Name	Rate	Rate Unit	Grow Stg.			
21 C35-20GPA Sanda Treflan	0.024	LB A/A PPI 1 PT/A PPI		57.5 abc	0.8 ghi	83.8 a-j
22 C35-27.5GPA None				0.0 s	2.0 c-i	78.8 b-k
23 C35-27.5GPA Dual Magnum	1	PT/A PRE		0.0 s	0.0 i	92.5 abc
24 C35-27.5GPA Sanda	0.024	LB A/A PRE		8.8 m-s	0.3 i	79.5 b-k
25 C35-27.5GPA Sulfentrazone	0.25	LB A/A PRE		10.0 m-s	1.0 f-i	92.5 abc
26 C35-27.5GPA Dual Magnum Sanda	1 0.024	PT/A PRE LB A/A PRE		17.5 k-o	0.5 hi	87.5 a-h
27 C35-27.5GPA Treflan	1	PT/A PPI		2.5 qrs	0.8 ghi	77.5 c-k
28 C35-27.5GPA Sanda Treflan	0.024	LB A/A PPI 1 PT/A PPI		65.0 a	0.0 i	90.0 a-f
29 C35-35GPA None				0.0 s	4.0 b-i	77.3 d-k
30 C35-35GPA Dual Magnum	1	PT/A PRE		0.0 s	0.3 i	93.5 ab
31 C35-35GPA Sanda	0.024	LB A/A PRE		2.5 qrs	1.3 f-i	95.0 a
32 C35-35GPA Sulfentrazone	0.25	LB A/A PRE		13.8 l-r	0.0 i	86.3 a-i
33 C35-35GPA Dual Magnum Sanda	1 0.024	PT/A PRE LB A/A PRE		17.5 k-o	0.0 i	93.8 ab
34 C35-35GPA Treflan	1	PT/A PPI		0.0 s	2.8 b-i	78.8 b-k
35 C35-35GPA Sanda Treflan	0.024	LB A/A PPI 1 PT/A PPI		61.3 ab	0.0 i	81.0 a-k
36 MS-37.5GPA None				0.0 s	4.8 b-g	75.0 f-k
37 MS-37.5GPA Dual Magnum	1	PT/A PRE		2.5 qrs	3.0 b-i	85.0 a-i
38 MS-37.5GPA Sanda	0.024	LB A/A PRE		0.0 s	5.5 b-e	76.3 e-k
39 MS-37.5GPA Sulfentrazone	0.25	LB A/A PRE		33.8 gh	2.3 c-i	81.0 a-k
40 MS-37.5GPA Dual Magnum Sanda	1 0.024	PT/A PRE LB A/A PRE		0.0 s	2.5 b-i	78.3 c-k
41 MS-37.5GPA Treflan	1	PT/A PPI		3.0 qrs	5.0 b-f	73.8 g-k
42 MS-37.5GPA Sanda Treflan	0.024	LB A/A PPI 1 PT/A PPI		12.3 m-s	1.3 f-i	78.8 b-k

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Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01
Trt No.	Treatment Name	Rate	Unit Grow Stg			
43	MS-56.3GPA None			0.0 s	6.5 b	73.8 g-k
44	MS-56.3GPA Dual Magnum	1 PT/A	PRE	0.0 s	1.5 e-i	92.5 abc
45	MS-56.3GPA Sandeia	0.024 LB A/A	PRE	0.0 s	5.8 bcd	78.8 b-k
46	MS-56.3GPA Sulfentrazone	0.25 LB A/A	PRE	35.0 fgh	2.0 c-i	90.0 a-f
47	MS-56.3GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	0.0 s	1.3 f-i	91.5 a-d
48	MS-56.3GPA Treflan	1 PT/A	PPI	0.0 s	2.8 b-i	76.3 e-k
49	MS-56.3GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	16.3 l-p	1.0 f-i	88.8 a-g
50	MS-75GPA None			0.0 s	5.0 b-f	78.3 c-k
51	MS-75GPA Dual Magnum	1 PT/A	PRE	0.0 s	0.8 ghi	82.5 a-k
52	MS-75GPA Sandeia	0.024 LB A/A	PRE	2.5 qrs	2.0 c-i	89.5 a-f
53	MS-75GPA Sulfentrazone	0.25 LB A/A	PRE	31.3 g-j	1.3 f-i	91.0 a-e
54	MS-75GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	2.0 rs	1.3 f-i	88.5 a-h
55	MS-75GPA Treflan	1 PT/A	PPI	0.0 s	5.5 b-e	69.5 jkl
56	MS-75GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	20.0 i-m	0.5 hi	79.3 b-k
57	C35-20GPA+MS-37.5GPA None			0.0 s	0.3 i	75.0 f-k
58	C35-20GPA+MS-37.5GPA Dual Magnum	1 PT/A	PRE	5.0 o-s	0.0 i	94.8 a
59	C35-20GPA+MS-37.5GPA Sandeia	0.024 LB A/A	PRE	9.3 m-s	0.0 i	94.8 a
60	C35-20GPA+MS-37.5GPA Sulfentrazone	0.25 LB A/A	PRE	13.8 l-r	0.0 i	92.5 abc
61	C35-20GPA+MS-37.5GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE	15.0 l-q	0.0 i	92.5 abc
62	C35-20GPA+MS-37.5GPA Treflan	1 PT/A	PPI	7.5 m-s	1.0 f-i	67.5 kl
63	C35-20GPA+MS-37.5GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI	51.3 b-e	0.0 i	91.0 a-e
64	C35-20GPA+MS-56.3GPA None			0.0 s	0.0 i	82.5 a-k

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Weed Code Crop Code Rating Data Type Rating Unit Rating Date				pepper injury percent May-12-01	CYPES number/ plot May-12-01	CYPZZ control percent Jul-09-01	
Trt No.	Treatment Name	Rate	Unit	Grow Stg			
65	C35-20GPA+MS-56.3GPA Dual Magnum	1 PT/A	PRE		3.8 p-s	0.0 i	91.0 a-e
66	C35-20GPA+MS-56.3GPA Sandeia	0.024 LB A/A	PRE		6.3 n-s	1.0 f-i	79.5 b-k
67	C35-20GPA+MS-56.3GPA Sulfentrazone	0.25 LB A/A	PRE		11.3 m-s	0.3 i	93.5 ab
68	C35-20GPA+MS-56.3GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE		18.8 j-n	0.0 i	93.5 ab
69	C35-20GPA+MS-56.3GPA Treflan	1 PT/A	PPI		2.5 qrs	1.8 d-i	75.0 f-k
70	C35-20GPA+MS-56.3GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI		32.5 ghi	1.0 f-i	77.5 c-k
71	C35-10GPA+MS25GPA None				0.0 s	0.3 i	86.3 a-i
72	C35-10GPA+MS25GPA Dual Magnum	1 PT/A	PRE		0.0 s	1.5 e-i	86.0 a-i
73	C35-10GPA+MS25GPA Sandeia	0.024 LB A/A	PRE		8.8 m-s	1.0 f-i	77.5 c-k
74	C35-10GPA+MS25GPA Sulfentrazone	0.25 LB A/A	PRE		10.8 m-s	0.8 ghi	77.5 c-k
75	C35-10GPA+MS25GPA Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE		25.5 h-l	0.0 i	91.3 a-e
76	C35-10GPA+MS25GPA Treflan	1 PT/A	PPI		0.0 s	1.0 f-i	77.5 c-k
77	C35-10GPA+MS25GPA Sandeia Treflan	0.024 LB A/A 1 PT/A	PPI PPI		42.5 d-g	0.8 ghi	78.8 b-k
78	Chloropicrin 125 lb Metam sodium 56.3 GP None				0.0 s	0.0 i	92.0 a-d
79	Chloropicrin 125 lb Metam sodium 56.3 GP Dual Magnum	1 PT/A	PRE		0.0 s	0.0 i	92.5 abc
80	Chloropicrin 125 lb Metam sodium 56.3 GP Sandeia	0.024 LB A/A	PRE		10.0 m-s	0.0 i	90.0 a-f
81	Chloropicrin 125 lb Metam sodium 56.3 GP Sulfentrazone	0.25 LB A/A	PRE		30.0 g-k	0.0 i	93.8 ab
82	Chloropicrin 125 lb Metam sodium 56.3 GP Dual Magnum Sandeia	1 PT/A 0.024 LB A/A	PRE PRE		25.0 h-l	0.0 i	93.8 ab
83	Chloropicrin 125 lb Metam sodium 56.3 GP Treflan	1 PT/A	PPI		0.0 s	0.0 i	87.5 a-h

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Weed Code				pepper	CYPES	CYPZZ
Crop Code				injury	number/	control
Rating Data Type				percent	plot	percent
Rating Unit				May-12-01	May-12-01	Jul-09-01
Rating Date						
Trt Treatment	Rate	Rate	Grow			
No. Name		Unit	Stg			
84 Chloropicrin 125 lb				55.0 a-d	0.0 i	93.8 ab
Metam sodium 56.3 GP						
Sandea	0.024 LB A/A	PPI				
Treflan	1 PT/A	PPI				
LSD (P=.05)				12.56	4.05	15.11
Standard Deviation				9.06	2.92	10.90
CV				76.28	185.74	12.88
Replicate F				2.024	0.699	4.148
Replicate Prob(F)				0.1115	0.5535	0.0070
Treatment F				13.241	2.174	2.147
Treatment Prob(F)				0.0001	0.0001	0.0001

Means followed by same letter do not significantly differ (P=.05, LSD)

Mean separations are based on the complete error term.

Trial Comments

OBJECTIVE: To compare 12 fumigant by 7 herbicide options for control of nutsedge and pepper tolerance.

Crop Tolerance:

- 1) A significant fumigant by herbicide interaction was noted for crop tolerance.
- 2) Pepper was tolerant to Dual applied at 1 pt/A under plastic regardless of fumigant.
- 3) Pepper showed minor and insignificant stunting from Sandea applied PRE at 0.024 lb A/A regardless of fumigant. There was a trend for less injury when applied in combination with metam sodium as compared to any other fumigant option.
- 4) Pepper was severely injured (30 to 39%) by sulfentrazone applied PRE under plastic when bromide, metam sodium, chloropicrin plus metam sodium or no fumigant were the fumigant option. However, when sulfentrazone was applied with any fumigant combination containing at least 20 gallons of Telone C-35 injury was less than 12%.
- 5) Dual plus Sandea injured pepper 2.5% when no fumigant was applied. Applying bromide, Telone C35 alone or mixed with metam sodium, or Chloropicrin injured pepper 14 to 25%. In contrast no injury was noted when Dual plus Sandea was applied with metam sodium (same trend as Sandea applied alone).
- 6) Treflan injured pepper less than 8%, regardless of fumigant.
- 7) Treflan plus Sandea injured Pepper 8% when no fumigant was applied. Applying metam sodium in combination with Treflan + Sandea did not increase injury; however, Telone C-35, Bromide, and Chloropicrin plus metam sodium increased injury by at least 25% with injury ranging from 33 to 65%.

Early Season Yellow Nutsedge Control:

- 1) Significant main effects of fumigant and herbicide were noted for nutsedge control.
- 2) All fumigant options reduced nutsedge emergence by at least 40% compared to no fumigant under the plastic.
- 3) The least effective fumigant options were metam sodium at 37.5, 56.3, and 75 GPA.
- 4) Trends were apparent for Bromide, Chloropicrin plus metam sodium, and Telone C35 plus metam sodium combinations to be the most effective options.
- 5) Treflan did not significantly reduce nutsedge populations.
- 6) Sulfentrazone, Dual Magnum, and Dual Magnum plus Sandea PRE as well as Sandea plus Treflan incorporated reduced nutsedge population similarly and were generally more effective than Sandea applied PRE under plastic.

Late Season Yellow Nutsedge Control:

- 1) Significant Main effects of fumigant and herbicide were noted.
- 2) The plastic alone controlled yellow nutsedge 56%. Pooled over fumigant option, nutsedge was controlled 78% when no herbicide was applied.
- 3) Metam sodium, regardless of rate, did not improve yellow nutsedge control compared to the no fumigant option.

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- 4) Chloropicrin plus metam sodium, Bromide, Telone C35, and Telone C35 plus Metam combinations controlled nutsedge similarly.
- 5) There was a trend throughout the data for the Chloropicrin plus metam sodium combination to be the most effective fumigant option.
- 6) Treflan had no impact on nutsedge control.
- 7) Dual Magnum plus Sandea, Sulfentrazone, and Dual Magnum alone controlled nutsedge similarly and tended to be the most effective herbicide options.

CONCLUSIONS:

Injury in this trial is very consistent but extremely confusing.

Metam sodium was the least effective fumigant option.

Dual, Dual + Sandea, and Sandea may all have a potential use for peppers under plastic.

We are screwed if we have to test all of the potentially new herbicides with the mass of fumigant options being implemented by our growers; however, this data suggest that may be necessary.

GENERAL COMMENTS

Mar-09-01:

- 1.) Took two days to put all treatments out.
 - 2.) Applied Telone with tilrovator followed by bed press.
 - 3.) Metam sprayed with boom an incorporated 3 to 5 inches with tilrovator in a single pass.
 - 4.) Co-applications of Telone C35 and metam were done with a single piece of equipment.
 - 5.) Bromide and Chloropicrin applied with superbedder.
 - 6.) PPI herbicide treatments were applied and incorporated with tilrovator. PRE herbicides were applied immediately after forming bed and just prior to laying plastic in a single operation. Herbicides applied at 20 gallons per acre.
- Jul-09-01: Ratings were compared to a true non-treated control (ie no plastic)

A LATE FALL RATING IN THE NEXT CROP WILL BE TAKEN FOR LONG TERM IMPACT.