Attachment 2

An Analysis of the Use and Benefits of Atrazine and Simazine in U.S. Field Corn and Grain Sorghum

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Executive Summary

Reported herein is a comprehensive simulation analysis of the use and benefits of chloro-*s*-triazine herbicides in United States field corn and grain sorghum using an analytical approach that was used to conduct similar assessments in 1995, 1997, 2010, and 2016. This analysis, initiated in July of 2019, used regionally specific data on weed incidence by species, crop yield losses by weed species, herbicide efficacy by weed species, and herbicide use data by active ingredient.

Impact to U.S. corn farmers. Corn yield was predicted to decline in all Farm Resource Regions (FRR) if triazine-containing (i.e., atrazine and simazine) herbicide treatments were not used. Yields were predicted to decline by 14 to 37 bushels/triazine-treated acre if current triazine-treated acres were apportioned to all remaining non-triazine treatments (State 1). Yields were predicted to decline by 11 to 28 bushels/triazine-treated acre if current triazine-treated acres were apportioned to all remaining non-triazine and non-glyphosate treatments (State 2). Averaged across triazine-treated acres in all FRR, corn yield was predicted to decline by 20 and 14 bushels/triazine-treated acre under State 1 and State 2 assumptions, respectively.

In general, weed control cost for corn farmers increased under State 1 and State 2 assumptions. Averaged across triazine-treated acres in all FRR, corn weed control cost was predicted to increase by $11.52/triazine-treated acre under State 1 assumptions and increase by $4.40/triazine-treated acre under State 2 assumptions (Table 12).

The net economic loss to U.S. corn farmers who use triazine herbicides was estimated at $4.6 billion and $3.1 billion for State 1 and State 2, respectively (Table 10).

Impact to U.S. grain sorghum farmers. Grain sorghum yield was predicted to decline in all Farm Resource Regions if triazine-containing (i.e., atrazine-containing) herbicide treatments were not used. In grain sorghum, atrazine was the only triazine whose use met the 2% of acres grown threshold for inclusion in the analysis.

Results for changes in cost, yield, and value for grain sorghum under State 1 assumptions are not discussed because State 1 is not a likely representation of what would happen in grain sorghum production because a glyphosate resistance trait is not available for grain sorghum. Therefore, glyphosate use in grain sorghum is limited to pre-planting or at-planting treatments.

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Furthermore, these treatments do not provide residual weed control. The triazine herbicides included in this sorghum analysis are used post-emergence and/or for residual weed control. Yields were predicted to decline by 30 to 40 bushels/triazine-treated acre if current triazine-treated acres were apportioned to all remaining non-triazine and non-glyphosate treatments (State 2). Averaged across triazine-treated acres in all FRR, grain sorghum yield was predicted to decline by 32 bushels/triazine-treated acre under State 2 assumptions (Table 12).

Weed control cost for grain sorghum farmers increased by $1.50 to $5.00 per triazine-treated acre. Averaged across triazine-treated acres in all FRR, grain sorghum weed control cost was predicted to increase by $1.91/triazine-treated acre under State 2 assumptions (Table 12).

The net economic loss to grain sorghum farmers in all FRR was estimated at $188.7 million to U.S. grain sorghum farmers who use triazine herbicides under State 2 assumptions (Table 11).

Materials and Methods

Process and analysis. The purpose of the study was to estimate the change in weed control costs and crop yield that might occur if atrazine and simazine were no longer used by U.S. corn and grain sorghum growers. The process and techniques used were the same as those used in previous analyses (Bridges, et al, 1994; Bridges, 1998; Bridges 2008; Bridges 2011; Bridges 2016). The process framework is depicted in Figure 1.

Input data. Conducting the analysis required a significant amount of detailed input data, which is summarized in Table 1. More detailed lists of input data can be obtained by written request to the author.

<u>Weed species to be included in the 2019 analysis</u>. A list of 23 weed species included in the 2019 analysis is shown in Table 2. The determination to include these weeds in the analysis was made after careful consideration of data from the 2010 analysis (Bridges, 2011), the 2015 WSSA survey (Van Wychen, 2016), a review conducted for the 2016 analysis (Gries and Hill, 2016), participants in this analysis (Wells, 2019), and independent third-party data (TPD, 2019). It was determined that insufficient change in percent infested acreage and projected percent damage had occurred since the previous analyses (Bridges, 2011 and 2016) to warrant conducting a new survey of weed scientists. Data considered in making this determination are included in Tables 3 through 5. Table 5 shows a cross-referenced tally with 70 to 90% agreement across the sources.

<u>Herbicide treatments included in the 2019 analysis</u>. Criteria for inclusion of treatments were the same for field corn and grain sorghum. Herbicides, as single active ingredients or mixtures, were included in the models if they were used on 2% or more of the U.S. base acres (TPD, 2019). Treatments used in the field corn analysis are shown in Table 6 and for grain sorghum in Table 7. Within a crop species, the list of treatments was the same for all Farm Resource Regions (FRR).

The number of treatment-specific base acres (TPD, 2019) was divided by the USDA planted acres to determine the percent of planted acres treated with each treatment. Yield and cost changes were calculated independently based on the percent of planted acres treated with each treatment.

Treatment costs included product (either active ingredient basis or product basis) plus adjuvant costs at $3.00/acre for treatments that required an adjuvant. A $6.70/acre application cost is internalized for all treatments in the process.

Herbicide targets by treatment used in the 2019 analysis. Five target weeds were identified for each of the herbicide treatments in each FRR and for each crop species. These target species were selected after considering FRR-specific weed infestations, FRR-specific potential damage, efficacy, and weed target information. Yield loss was calculated based on the five target weed species for each triazine-containing treatment. The same, treatment-specific target weeds were used to calculate weed control and yield loss for each potential alternative treatment.

Acreage, production, price, and value. Acreage and yield were obtained from the USDA for the 2016, 2017, and 2018 crop years by FRR for both field corn and grain sorghum (Tables 8 and 9). Average planted acres and average yield (bu/acre) were calculated from these data. Corn price, $3.43/bushel, was computed as the average of 36 months beginning on January 1, 2016 and ending on December 31, 2018. Grain sorghum price, $2.82/bushel, was computed as the average of 3 annual values, one each for 2016, 2017, and 2018.

Aggregation, Farm Resource Regions (FRR) and models. Models were developed to simulate cost and yield changes for 100% of U.S. field corn and grain sorghum acres. However, acreage was aggregated differently for the two crops. For example, for field corn 92.0% of U.S. acreage was planted in four FRR – Heartland, Northern Crescent, Prairie Gateway, and Northern Great Plains. The remaining 8.0% of U.S. corn acreage was combined into one contrived FRR called the Rest of Country. A model was developed for each of the five FRR, representing 100% of U.S. field corn acres (Table 8).

For grain sorghum, 90.2% of U.S. acreage was planted in two FRR – Prairie Gateway and Fruitful Rim. The remaining 9.8% of U.S. grain sorghum acreage was combined into one contrived FRR called the Rest of Country. A model was developed for each of the three FRR, representing 100% of U.S. grain sorghum acres (Table 9).

Substitution analyses. A three-step substitution analysis was used to estimate yield and cost changes that together reflect the value of the treatments in the FRR under current use conditions. In other words, the analysis reflects certain aspects of farmer behavior based on the assumption that current use is a proxy for efficacy, perceived value, return on investments, etc. It also uses direct biological and economic information, like efficacy and cost of treatment, as a basis for predicted cost and yield changes

Determining accurate weighted cost and yield change estimates that could result from not using triazine herbicides required a three-step process. The first step calculated the treatment cost and value of yield that was preserved by use of a triazine-containing treatment. The calculation used estimates of weed infestation and damage, percent planted acres treated with the treatment, and yield potential on an FRR-specific and crop-specific basis. The calculation was made using five weed species that were targeted with the treatment. The step resulted in per acre calculated cost and per acre value for the crop yield that was derived by using the treatment (as a result of controlling weeds that would reduce yield). In other words, the first step established the baseline value (benefit) use to determine the change in benefit associated with potential alternative treatments.

The second step calculates the comparative value (benefit) of each putative alternative. This is accomplished by calculating the change in treatment cost and the change in yield, hence value of the crop that is produced, for each of the remaining, non-triazine treatments in the suite of alternative treatments (see State discussion later). Cost, yield, and value, changes were made for each putative alternative using the same five targeted weed species for each of the triazine-containing treatments within the FRR. This step was repeated for all triazine-containing treatments in each FRR for each crop species. For field corn there were seven triazine-containing treatments in each FRR. Therefore, the step was repeated seven times for each FRR. For grain sorghum there were four triazine-containing treatments. Therefore, the step was repeated four times for each FRR.

<u>Apportionment</u>. The third step required that current triazine-treated acres in the FRR be apportioned to putative alternative treatments, resulting in a set of cost and yield changes on the FRR acres that were treated with triazines (replacement acres). The challenge was to define what the future would look like if triazines are not used. Several factors were considered in defining possible future states:

1. What is a future state that reflects as nearly as possible the current state with the only change being removal of triazine-containing treatments?
2. Since glyphosate is a co-dominant feature in the current market (especially for field corn), do future states that shift current triazine acres to more glyphosate represent a likely scenario given the increasing prevalence of glyphosate-resistant weeds?
3. What happens if the prevalence of glyphosate-resistant weeds increases and weed control becomes more challenging with treatments that are heavily dependent on glyphosate?

Considering these factors, two future states were envisioned and used in the apportionment process:

State 1	All triazine acres in the FRR were apportioned to <u>all</u> **non-triazine treatments**, proportional to current percent of planted acres treated with each treatment.
State 2	All triazine acres in the FRR were apportioned to <u>all</u> **non-triazine and non-glyphosate treatments**, proportional to current percent of planted acres treated with each treatment. Note: this does not change current glyphosate use. It simply means that additional acres are not apportioned to glyphosate.

There were 25, 18, and 15 treatments in the Current State, State 1, and State 2 for field corn, respectively. There were 8, 4, and 3 treatments in the Current State, State 1, and State 2 for grain sorghum, respectively, Tables 6 and 7. Weighted average cost and yield changes were calculated for each crop and FRR based on these state definitions.

<u>All-in combinations</u>. The previously described processes were designed to reflect certain aspects of current usage within the FRR. For example, current use of the treatments, based on TPD, 2019, drove the calculations of benefit. Also, each substitution calculation and apportionment process were based on the target weed species for each triazine treatment. In turn, yield and cost change were calculated for each putative alternative based on the same target weeds. In essence, farmer behavior was captured in the analysis.

Another method was used to estimate benefits derived from triazine herbicide use. It did not consider current use information or targeting. Therefore, it results in a bioeconomic analysis of the potential value of herbicides within the crop and the FRR based on the prevalence of weeds, the potential damage that would result from failure to control, and the efficacy of the individual treatments. In other words, the protection value (value of crop yield preserved based on weed control) of each treatment was calculated based on efficacy, infestation, and damage by all weed species in the FRR, regardless of current use of the individual treatment.

Three separate analyses were conducted. The first calculation assumes that one, and only one, treatment will be used on each planted acre. In the current analysis these were all one-pass treatments. This analysis was referred to as the one-way analysis.

A second calculation was made assuming that all treatments (25 for corn and 8 for grain sorghum) could be used in all possible two-way combinations, resulting in 300 combinations for corn and 28 combinations for grain sorghum.

A third calculation was made assuming that all treatments (25 for corn and 8 for grain sorghum) could be used in all possible three-way combinations, resulting in 2,300 combinations for corn and 56 combinations for grain sorghum.

Results and Discussion

<u>Substitution and apportionment analyses</u>

<u>Yield and cost changes – corn</u>. Corn yield was predicted to decline with removal of the seven (7) triazine treatments under State 1 and State 2 in all FRR (Table 10). Corn yields were estimated to decline by 14 to 37 bu/triazine-treated acre for State 1 and by 11 to 28 bu/triazine-treated acre for State 2. Averaged across the U.S. triazine-treated corn acreage, yield was predicted to decline by 19.9 and 14.3 bushels per triazine-treated acre for State 1 and State 2, respectively (Table 12).

The cost to control weeds in corn was predicted to increase with removal of the seven (7) triazine treatments under State 1 and State 2 in all FRR (Table 10). The cost to control weeds was predicted to increase by $10.48 to $16.17 per triazine-treated acre under State 1 conditions and by $3.05 to $8.12 per triazine-treated acre under State 2 conditions. Averaged across the U.S. triazine-treated corn acreage, the cost to control weeds was predicted to increase by $11.52 and $4.40 per triazine-treated acre for State 1 and State 2, respectively (Table 12).

<u>Direct economic impact to corn farmers who use triazines</u>. The direct projected economic impact to the farmer occurs as a result of predicted yield changes (which translate into dollars per acre) and to the change in costs associated with putative replacement treatments. The net change (loss) to corn farmers who use triazine herbicides was estimated to be -$4.6 billion and -$3.1 billion annually for State 1 and State 2, respectively (Table 10).

Yield and cost changes – grain sorghum. Because glyphosate cannot be used after grain sorghum emerges, State 1 for grain sorghum represents an unlikely scenario of cost and yield changes in the absence of triazines. Therefore, State 1 results are not discussed here. Grain sorghum yield was predicted to decline with removal of the four (4) triazine treatments under State 2 in all FRR (Table 11). Grain sorghum yields were estimated to decline by 14.6 to 27.2 bu/triazine-treated acre for State 2. Averaged across the U.S. triazine-treated grain sorghum acreage, yield was predicted to decline by 25.3 bushels/triazine-treated acre for State 2 (Table 12).

Weed control costs were predicted to increase by $1.49 to $5.00/triazine-treated under State 2 assumptions across the three FRR (Table 11). Averaged across the U.S. triazine-treated grain sorghum acreage, weed control cost increased by $1.91 per triazine-treated acre under State 2 (Table 12).

Direct economic impact to grain sorghum farmers who use triazines. The net change (loss) to grain sorghum farmers who use triazine herbicides was estimated to be -$188.7 million annually for State 2 (Table 11).

Yield and cost changes for U.S. corn farmers who use triazines across years. Treatments included in the corn analysis have changed over the years. Some treatments are no longer used and new ones have been added. Prices for herbicide treatments, both absolute and relative, have changed over the years, as well as the percent of acres on which they are used. These factors, along with the weed species present and the efficacy of the treatments used, have a significant impact on yield and cost changes that are predicted to occur if a treatment is no longer used. However, the effectiveness, both biologically and economically, of the triazine herbicides, and especially that of atrazine, is so outstanding that it remains a very dominant player in U.S. corn production. It is heavily relied on by U.S. corn farmers, and rightfully so. The importance of atrazine to U.S. corn farmers is obvious when comparing the corn yield changes that are predicted to occur if atrazine were no longer used (Table 13).

Three separate analyses over the past ten years, 2010, 2016, and 2019, show that U.S. corn yield will likely decline across all FRR, regardless of the replacement scenario, if atrazine is no longer available, indicating that a suitable alternative for atrazine has not been developed. In fact, averaged across years, FRR, and replacement scenarios (n=30), corn yield is predicted to decline by 17.7 bushels per triazine treated acre and weed control cost is predicted to rise by $2.95 per triazine treated acre.

All-in combination

The underlying rationale for the high dependence on atrazine for corn weed control is demonstrated when estimating the bioeconomic benefits associated with atrazine use in corn based in the absence of current market trends. That is, when just looking at efficacy and cost, the benefits are readily apparent.

Table 14 shows the results of an analysis that estimated the weed control, yield, and cost factors if the Heartland FRR was treated as a single field with weed infestations as indicated by the best available data and assuming that one, and only one treatment, was used across the entire FRR. The calculations were made independently for each of the 25 corn treatments in the Heartland

FRR, and results are sorted from highest net protection value (NPV) to lowest. Three of the top five treatments were atrazine-containing treatments.

It has been well established, both in research plots and in field use, that atrazine is a superb mix partner for many corn herbicides. So, it is not surprising that, when considering two- and three-way combinations of the 25 corn herbicide treatments in the Heartland FRR, the results show that atrazine is the most preferred component of the currently available treatments.

Table 14 shows that among the top 50 of 300 two-combinations for corn weed control in the Heartland FRR, atrazine occurred in either the first or second sequence 40 times and that atrazine occurred in both sequences 10 times. No other herbicide was used in combination as frequently as atrazine.

Furthermore, among the top 50 of 2,300 three-way combinations, atrazine occurred 15, 50, and 3 times as a component in the first, second and third sequences, respectively.

References

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Figure 1. Schematic of analysis process.

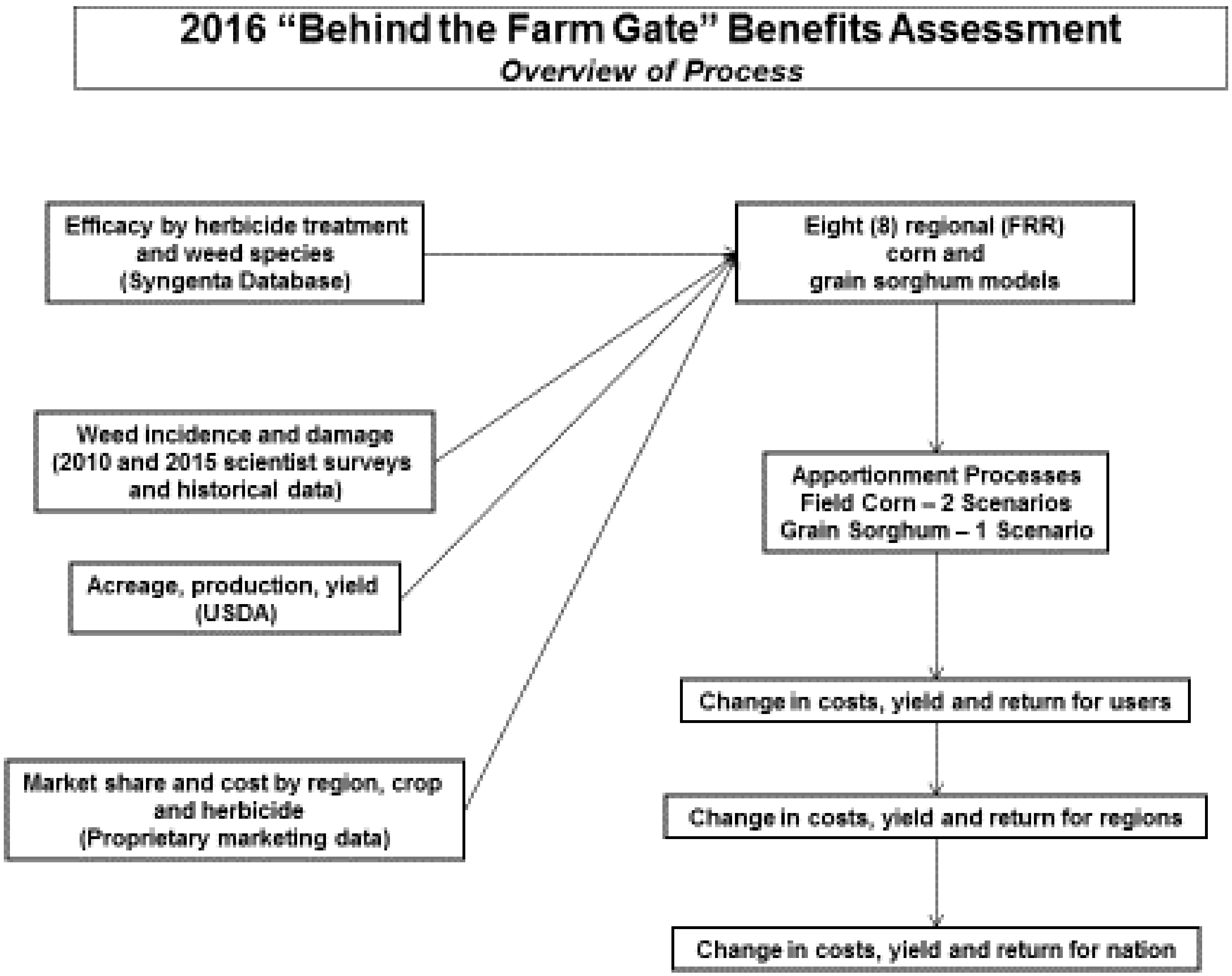

Table 1. Data and source used in the analysis.

Data type	Source(s)
Efficacy data – percent weed control by weed species (23) and herbicide treatments (25 for field corn; 8 for grain sorghum)	Syngenta database of public and private research trials on weed control in corn and grain sorghum - corn ~7,800 and grain sorghum >2,200.
Use, average of 2016-2018 crop year (percent treated acres by treatment and FRR).	Third-party data
Cost (avg 2016-2018) – proprietary data by treatment	Third-party data
Weed incidence and potential damage – by weed species (23), by FRR	2010 survey of weed scientists 2015 surveys of weed scientists Third-party data Weed control ratings from several state extension publications across FRR
Target weed species by herbicide treatment, FRR and crop.	Determined based on efficacy, infestation and loss data by crop and FRR
Planted acres by FRR – average of 2016-2018 crop year	United States Department of Agriculture
Estimated yield by FRR – average of 2016-2018 crop year	United States Department of Agriculture
Corn price – average of 36 monthly values for 2016-2018 Grain sorghum price – average of 3 yearly values for 2016-2018	United States Department of Agriculture

Table 2. Weeds included in the 2019 Heartland FRR corn analysis.

Weed no.	Code	Common name	FRR acres infested (%)	Yield loss if not controlled (%)
1	ABUTH	Velvetleaf	54	30
2	AGRRE	Quackgrass	3	9
3	AMAPA	Palmer pigweed	13	43
4	AMATZ	Common/Tall waterhemp	49	26
5	AMAZZ	Pigweeds (all others)	51	30
6	AMBZZ	Other ragweeds	24	33
7	AMBTR	Giant ragweed	33	49
8	BRAPP	Broadleaf signalgrass	2	10
9	CASOB	Sicklepod	0	5
10	CHEAL	Common lambsquarters	67	31
11	CIRZZ	Thistles	7	7
12	CYPZZ	Nutsedges	12	23
13	DATST	Jimsonweed	2	13
14	DIGZZ	Crabgrasses	26	15
15	ECHCG	Barnyardgrass	25	22
16	ERIZZ	Horseweed/Marestail	36	16
17	HELZZ	Sunflower(s)	22	50
18	IPOZZ	Morningglories	40	25
19	KCHSC	Kochia	8	23
20	PANDI	Fall panicum	28	25
21	POLZZ	Smartweeds	20	28
22	SETZZ	Foxtails	81	38
23	XANZZ	Cockleburs	36	34

Table 3. List of weeds by various sources for the Heartland Region.

2015 WSSA Common[1]	2015 WSSA Troublesome[1]	2009 Heartland FRR (% Infested)[2]	2009 Heartland FRR (% Damage)[2]
Common waterhemp	Common waterhemp	Foxtails	Foxtails
Giant foxtail	Giant ragweed	Common Lambsquarters	Common Lambsquarters
Common lambsquarters	Common lambsquarters	Velvetleaf	Velvetleaf
Giant ragweed	Morningglory spp.	Pigweeds (all others)	Giant Ragweed
Velvetleaf	Palmer amaranth	Common/Tall Waterhemp	Pigweeds (all others)
Common ragweed	Giant foxtail	Morningglories	Common/Tall Waterhemp
Fall panicum	Conyza canadensis	Horseweed / Marestail	Cockleburs
Morningglory spp.	Common ragweed	Cockleburs	Sunflower(s)
Horseweed / Marestail	Barnyardgrass	Giant Ragweed	Morningglories
Ivyleaf morningglory	Fall panicum	Fall Panicum	Other ragweeds

[1]Van Wychen L (2016).
[2]Bridges, D. C. 2011.

Table 4. Target weeds used for atrazine-containing herbicides in the 2019 analysis for the Heartland FRR.

2019 Heartland corn targets	Timing	Weed Species				
Atrazine	POST	Waterhemp	Giant ragweed	Common lambsquarters	Morningglories	Cockleburs
Atrazine	PRE	Waterhemp	Giant ragweed	Common lambsquarters	Morningglories	Cockleburs
Acetochlor + Atrazine	PRE	Foxtails	Waterhemp	Common lambsquarters	Velvetleaf	Cockleburs
Atrazine + Bicyclopyrone + Mesotrione + *S*-Metolachlor	PRE	Waterhemp	Foxtails	Giant ragweed	Velvetleaf	Cockleburs
Atrazine + *S*-Metolachlor	PRE	Foxtails	Waterhemp	Common lambsquarters	Velvetleaf	Cockleburs
Atrazine + Mesotrione + *S*-Metolachlor	PRE	Waterhemp	Velvetleaf	Foxtails	Common lambsquarters	Giant ragweed
Simazine	PRE	Common lambsquarters	Pigweeds	Other ragweeds	Crabgrasses	Fall panicum

Table 5. Comparison of weeds listed by various sources considered for use in the 2019 analysis, Heartland FRR.

Weed	2015 WSSA	2015 WSSA	2011 Bridges	2011 Bridges	2011 Bridges
	Common	Troublesome	% Infested	% Damage	ATZ Targets
Common waterhemp	1	1	1	1	
Giant foxtail	1	1	1	1	1
Common lambsquarters	1	1	1	1	1
Giant ragweed	1	1	1	1	1
Velvetleaf	1		1	1	1
Common ragweed	1	1		1	1
Fall panicum	1	1	1		
Morningglory spp.	1	1	1	1	1
Horseweed / Marestail	1	1	1		
Ivyleaf morningglory	1	1	1	1	1
Totals	**10**	**9**	**9**	**8**	**7**

Table 6. Herbicide treatments and costs included in the 2019 analysis for field corn.

Current state	**Included in State 1?**	**Included in State 2?**
Glyphosate AE	Yes	No
Glyphosate BE	Yes	No
Atrazine BE	No	No
Atrazine AE	No	No
Acetochlor + Atrazine BE	No	No
S-metolacholor + Glyphosate + Mesotrione AE	Yes	No
Acetochlor + Clopyralid + Flumetsulam BE	Yes	Yes
S-Metolachlor + Mesotrione +Atrazine BE	No	No
Dicamba + Diflufenzopyr AE	Yes	Yes
Isoxaflutole + Thiencarbazone-methyl BE	Yes	Yes
S-metolachlor + Atrazine BE	No	No
Mesotrione AE	Yes	Yes
Tembotrione + Safener AE	Yes	Yes
Topramezone AE	Yes	Yes
Acetochlor BE	Yes	Yes
Dimethenamid-P + Saflufenacil BE	Yes	Yes
Acetochlor + Clopyralid + Flumetsulam AE	Yes	Yes
Isoxaflutole BE	Yes	Yes
Dicamba AE	Yes	Yes
Tembotrione + Thiencarbazone-methyl AE	Yes	Yes
Simazine BE	No	No
S-metolachlor BE	Yes	Yes
Atrazine + Bicyclopyr + Mesotrione + *S*-metolachlor BE	No	No
Acetochlor + Clopyrlid + Mesotrione AE	Yes	Yes
Dimethenamid-P + Topramezone AE	Yes	Yes

Table 7. Herbicide treatments and costs included in the 2019 analysis for grain sorghum.

Current State	Included in State 2?
Glyphosate BE	No
Atrazine BE	No
Atrazine AE	No
S-metolachlor BE	Yes
2,4-D AE	Yes
Acetochlor + atrazine BE	No
S-metolachlor + atrazine BE	No
Bromoxynil + pyrasulfotole AE	Yes

Table 8. Average field corn acreage and yield by FRR for the 2016-2018 crop years.

Farm Resource Region (FRR)	FRR Corn Acreage (planted) Average of 2016-2018	% of U.S. corn acreage	Cumulative % of U.S. corn acreage	Corn yield (bu/planted acre)
Heartland	48,703,400	54.3%	54%	182.4
Northern Crescent	10,901,600	12.2%	66%	151.3
Northern Great Plains	9,441,733	10.5%	77%	137.4
Prairie Gateway	13,185,833	14.7%	92%	127.3
The following FRR were combined into one FRR, the Rest of Country				
Eastern Uplands	*1,479,867*	*1.6%*	*93%*	*146.4*
Southern Seaboard	*2,511,000*	*2.8%*	*96%*	*138.3*
Fruitful Rim	*1,205,033*	*1.3%*	*97%*	*156.5*
Basin and Range	*40,467*	*<0.1%*	*98%*	*166.1*
Mississippi Portal	*2,237,500*	*2.4%*	*100%*	*165.8*
Rest of Country	7,473,867	8.3%		155.0
U.S. Total	**89,706,433**	**100%**		

[1]7,473,867 is the total field corn planted acres for the Southern Seaboard, Mississippi Portal, Fruitful Rim, Eastern Uplands, and Basin Range, which comprises the "Rest of the Country" for field corn. The average yield for the "Rest of the Country" was 155.0 bushels/acre, which is weighted by planted acres.

Table 9. Average grain sorghum acreage and yield by FRR for the 2016 – 2018 crop years.

Farm Resource Region (FRR)	**FRR grain sorghum acreage (planted) Average of 2016-2018**	**% of U.S. grain sorghum acreage**	**Cumulative % of U.S. grain sorghum acreage**	**Grain sorghum yield (bu/planted acre)**
Prairie Gateway	4,345,900	78.5%	78.5%	66.0
Fruitful Rim	644,166.7	11.6%	90.2%	70.0
The following FRR were combined into one FRR, the Rest of Country				
Northern Great Plains	471,467	8.5%	98.7%	83.0
Heartland	34,233	0.6%	99.3%	99.0
Mississippi Portal	23,800	0.4%	99.7%	86.0
Eastern Uplands	8,400	0.2%	99.9%	80.0
Southern Seaboard	6,200	0.1%	100.0%	87.0
Northern Crescent	0	0.0%	100.0%	0.0
Basin and Range	0	0.0%	100.0%	0.0
Rest of Country	544,100	9.8%		87.0
U.S. Total	**5,534,167**	**100%**		

[1]544,100 is the total grain sorghum planted acres for the Heartland, Mississippi Portal, Northern Great Plains, Eastern Uplands, Southern Seaboard, Northern Crescent, and Basin & Range, which comprises the "Rest of the Country" for grain sorghum. The average yield for the "Rest of the Country" was 87.0 bushels/acre, which is weighted by planted acres.

Table 10. Cost and yield changes for State 1 and State 2 by FRR – corn.

State 1					
Region (FRR)	**Cost Change ($/triazine treated acre)**	**Yield Change (bu/triazine treated acre)**	**Value of yield change ($/triazine treated acre)**	**Net change ($/triazine treated acre)**	**Net change on triazine treated acres in FRR**
Heartland	$10.64	-14.06	-$48.24	-$58.88	-$1,949,915,345
Northern Crescent	$10.48	-24.82	-$85.15	-$95.62	-$406,548,242
Northern Great Plains	$14.08	-14.77	-$50.67	-$64.76	-$256,796,139
Prairie Gateway	$11.30	-29.00	-$99.47	-$110.77	-$1,183,054,676
Rest of Country	$16.17	-37.23	-$127.69	-$143.87	-$795,671,954
				U.S. Total	**-$4,591,986,355**
State 2					
Region (FRR)	**Cost Change ($/triazine treated acre)**	**Yield Change (bu/triazine treated acre)**	**Value of yield change ($/triazine treated acre)**	**Net change ($/triazine treated acre)**	**Net change on triazine treated acres in FRR**
Heartland	$3.55	-11.39	-$39.05	-$42.60	-$1,410,937,760
Northern Crescent	$3.05	-27.81	-$95.38	-$98.43	-$418,501,973
Northern Great Plains	$8.12	-11.98	-$41.09	-$49.20	-$195,112,899
Prairie Gateway	$4.65	-12.37	-$42.44	-$47.09	-$502,947,339
Rest of Country	$7.34	-26.96	-$92.46	-$99.80	-$551,953,591
				U.S. Total	**-$3,079,453,564**

Table 11. Cost and yield changes for State 2 by FRR – grain sorghum.

State 2					
Region (FRR)	**Cost Change ($/triazine treated acre)**	**Yield Change (bu/triazine treated acre)**	**Value of yield change ($/triazine treated acre)**	**Net change ($/triazine treated acre)**	**Net change on triazine treated acres in FRR**
Prairie Gateway	$1.49	-27.2	-$76.80	-$78.30	-$170,133,858.91
Fruitful Rim	$5.00	-14.8	-$41.87	-$46.86	-$12,377,401.26
Rest of Country	$2.52	-14.6	-$41.11	-$43.64	-$6,173,069.53
				U.S. Total	**-$188,684,330**

Table 12. Predicted weighted national average cost and yield change for current triazine users.

Parameter	**Corn**		**Grain Sorghum**
	State 1	**State 2**	**State 2**
Average cost change to triazine users ($/triazine treated acre)	$11.52	$4.40	$1.91
Average yield change to triazine users ($/triazine treated acre)	-19.9	-14.3	-25.3
Average change in value of production to triazine users ($/triazine treated acre)	-$68.28	-$49.11	-$71.27
Average net change to triazine users ($/triazine treated acre)	-$79.80	-$53.51	-$73.18

Table 13. Comparison of cost and yield change for Heartland FRR corn farmers with and without triazines – comparing results from 2010, 2016, and 2019.

Yield change comparisons	Bushels per current triazine treated acre					
	2010 - Scenario 1	2010 - Scenario 2	2016 - State 1	2016 - State 2	2019 - State 1	2019 - State 2
Heartland	-15.16	-17.6	-18.3	-14.1	-14.06	-11.39
Northern Crescent	-10.76	-16.3	-25.3	-24.6	-24.82	-27.81
Northern Great Plains	-6.73	-11	-17.6	-13.2	-14.77	-11.98
Prairie Gateway	-4.41	-5.7	-25.9	-8.4	-29	-12.37
Rest of Country	-11.4	-17.5	-41.2	-17.6	-37.23	-26.96

Cost change comparisons	$ per current triazine treated acre					
	2010 - Scenario 1	2010 - Scenario 2	2016 - State 1	2016 - State 2	2019 - State 1	2019 - State 2
Heartland	-$4.16	-$1.46	-$2.02	$2.37	$10.64	$3.55
Northern Crescent	-$8.89	-$5.54	-$4.89	$0.09	$10.48	$3.05
Northern Great Plains	$0.37	$2.24	-$0.09	$4.81	$14.08	$8.12
Prairie Gateway	-$3.56	-$1.32	-$2.59	$3.54	$11.30	$4.65
Rest of Country	$12.00	$0.07	$0.65	$7.39	$16.17	$7.34

Table 14. Single treatment analysis: net protection value (NPV), total treatment expenditures, net return to treatment, and return ratio for herbicide use by corn farmers in the Heartland FRR – 2019 analysis.

Treatment and timing	Millions $			Return Ratio
	NPV	TotCost	NRT	
S-metolacholor + Glyphosate + Mesotrione AE	$22,568.62	$2,469.75	$20,098.87	9.138
Atrazine + Bicyclopyr + Mesotrione + S-metolachlor BE	$22,210.54	$2,105.94	$20,104.60	10.547
S-Metolachlor + Mesotrione +Atrazine BE	$22,166.68	$1,899.92	$20,266.76	11.667
Acetochlor + Atrazine BE	$21,003.08	$1,216.12	$19,786.96	17.271
Dimethenamid-P + Saflufenacil BE	$20,722.30	$1,265.31	$19,456.98	16.377
Isoxaflutole + Thiencarbazone-methyl BE	$20,699.51	$1,299.89	$19,399.61	15.924
S-metolachlor + Atrazine BE	$20,521.72	$1,241.45	$19,280.27	16.53
Glyphosate AE	$20,420.98	$1,689.03	$18,731.95	12.09
Dicamba + Diflufenzopyr AE	$19,867.99	$1,670.53	$18,197.46	11.893
Tembotrione + Safener AE	$19,832.91	$1,057.84	$18,775.07	18.749
Atrazine AE	$19,783.20	$715.94	$19,067.26	27.632
Isoxaflutole BE	$19,126.64	$1,143.56	$17,983.09	16.726
Acetochlor + Clopyralid + Flumetsulam AE	$18,807.20	$950.20	$17,857.00	19.793
Tembotrione + Thiencarbazone-methyl AE	$18,543.81	$1,150.86	$17,392.95	16.113
Topramezone AE	$18,124.26	$1,062.71	$17,061.55	17.055
Atrazine BE	$17,843.34	$610.25	$17,233.08	29.239
Dicamba AE	$17,570.16	$686.23	$16,883.93	25.604
Mesotrione AE	$17,500.82	$826.50	$16,674.33	21.175
Acetochlor BE	$16,745.79	$1,122.13	$15,623.66	14.923
Acetochlor + Clopyralid + Mesotrione AE	$16,482.61	$2,083.53	$14,399.08	7.911
Dimethenamid-P + Topramezone AE	$16,358.26	$1,239.01	$15,119.25	13.203
Simazine BE	$14,247.93	$737.86	$13,510.07	19.31
S-metolachlor BE	$13,833.30	$1,007.19	$12,826.12	13.735
Acetochlor + Clopyralid + Flumetsulam BE	$13,041.38	$1,096.31	$11,945.06	11.896
Glyphosate BE	$11,134.72	$1,542.92	$9,591.80	7.217

Note: Figures in this table represent predicted net protection value, treatment expenditures, net return to treatment, and return ratio, assuming that one, and only one, treatment is used on all planted corn acres in the Heartland FRR. Net protection value is calculated on all weeds in the region for each treatment, not just the target weeds for that treatment.

Table 15. Summary of two-way and three-way combinations analyses for corn in the Heartland FRR – 2019.

Two-way combinations	
Number of combinations	300
Out of the top 50 treatment combinations (ranked on NPV), either the first or the second sequence included atrazine.	40
Out of the top 50 treatment combinations (ranked on NPV), both the first and the second sequence included atrazine.	10
Three-way combinations	
Number of combinations	2300
Out of the top 50 treatment combinations (ranked on NPV), atrazine was included in one out of three treatments in the sequence.	15
Out of the top 50 treatment combinations (ranked on NPV), atrazine was included in two out of three treatments in the sequence.	50
Out of the top 50 treatment combinations (ranked on NPV), atrazine was included in three out of three treatments in the sequence.	3