UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF CHEMICAL SAFETY
AND POLLUTION PREVENTION

October 26, 2020

MEMORANDUM

SUBJECT: Assessment of the Benefits of Dicamba Use in Genetically Modified, Dicamba-Tolerant Soybean Production (PC# 100094, 128931)

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Product Review Panel Date: September 9, 2020

SUMMARY

This document describes the benefits of registering dicamba for preemergence and postemergence use on dicamba-tolerant (DT) soybean. Soybean is the second highest acreage crop in the United States, with $38.7 billion worth of soybean grown each year on 84.8 million acres. In 2017 and 2018, growers used dicamba on 8% of all U.S. soybean acres (DT and non-DT) prior to crop emergence and on 17% of all U.S. soybean acres after crop emergence. Postemergence dicamba is primarily used to target herbicide-resistant Palmer amaranth, waterhemp, kochia, ragweed, and marestail but is effective at controlling a range of broadleaf weed species.

The dicamba tolerant system was created to address weed populations with resistance to glyphosate (Weed Science Society of America [WSSA] Group 9 herbicide), ALS (acetolactate synthase) inhibitor herbicides (WSSA Group 2) and PPO (protoporphyrinogen oxidase) inhibitor herbicides (WSSA group 14). The registration of dicamba in DT soybean would give growers additional flexibility in choosing varieties for managing herbicide-resistant weed populations, thereby prolonging the effectiveness of currently available control options for herbicide-resistant weed species. For areas where dicamba products cannot be used on DT soybean, there are effective alternative weed control programs currently available for the control of problematic broadleaf weeds in soybean. However, the number of postemergence herbicide options is very limited; therefore, many soybean growers can benefit from the registration of dicamba for use in DT soybean.

In addition to postemergence application, dicamba in DT soybean has utility prior to crop emergence. Dicamba products intended for use on non-DT soybean include a preplant restriction of a specified number of days and amount of rainfall to between dicamba application and planting to avoid soybean injury from dicamba. Since DT soybean are highly tolerant of dicamba, dicamba products intended for use on DT soybean do not include preplant restrictions increasing the flexibility for preemergence dicamba use. This increased flexibility of preemergence use of dicamba on DT soybean is another benefit of the registration of these dicamba products.

Relative to some herbicide programs (*e.g.,* a 2,4-D based program) postemergence dicamba may reduce grower costs by $12-$14 per acre, which may account for 4%-7% of grower net operating revenue, depending on the region. Seed costs and rebates offered by seed and chemical manufacturers can vary widely and affect the overall cost of the herbicide program.
In addition, the further development of dicamba-resistant weed populations would reduce the benefits of this technology in areas where dicamba resistant populations emerge. For example, additional herbicide applications may be necessary to achieve adequate weed control where species are experiencing decreased susceptibility to dicamba, increasing the cost of the postemergence dicamba program relative to alternative herbicide programs. Dicamba-resistant Palmer amaranth have been confirmed in two states. Furthermore, antagonism between glyphosate and antagonism may require growers facing pressure from grass weeds to make additional passes through the field. Risk control measures, discussed in *Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to*

Users and Non-Users from Proposed Registrations (Chism et al., 2020), may also impinge on the benefits of dicamba, depending on the measure itself.

Overall, BEAD concludes that the registration of dicamba for preemergence and postemergence use in DT soybean gives many growers increased flexibility in their choice of seed varieties. Growers using DT seed have the option to use dicamba as a cost-effective way to control problematic herbicide-resistant broadleaf weed species, and as an additional tool to delay the further development of herbicide resistance.

INTRODUCTION

The Federal Insecticide Fungicide and Rodenticide Act (FIFRA) Section 3(c) mandates that the Environmental Protection Agency (EPA or Agency) evaluate any proposed use of pesticides to ensure that it does not pose unreasonable adverse effects to human health and the environment. In determining whether effects of pesticide use are unreasonable, FIFRA requires that the Agency consider the risks and benefits of any use of the pesticide.

The Agency is evaluating applications for registration of dicamba that is applied to DT soybeans after soybean emergence. This type of application is also called a postemergence application referring to the herbicide being applied to the emerged DT soybeans to remove existing weeds in the crop (also referred to as "Over-the-Top" or OTT use). This use differs from traditional (pre-DT soybean) dicamba use in soybean, which was restricted to preplant use only.

The Agency registered three postemergence dicamba products for use on genetically modified herbicide-resistant soybean in 2016 (Engenia, EPA Reg. No. 7969-345; Fexapan, EPA Reg. No. 352-913; Xtendimax with Vaporgrip Technology, EPA Reg. No. 524-617). These postemergence dicamba products were granted an extension of registration on October 31, 2018 (EPA, 2018e). The registrations of these three products were vacated on June 3, 2020 by the United States Court of Appeals for the Ninth Circuit (*National Family Farm Coalition, et. al. v. EPA*, 960 F.3d 1120 (9th Cir. 2020)). On April 5, 2019, EPA registered a product containing a combination of dicamba and S-metolachlor for postemergence use on dicamba-tolerant cotton and soybeans (Tavium, EPA Reg. No. 100-1623). This combination of active ingredients was previously an approved tank mix, and as such, was already used postemergence cotton and soybeans. The registration for this dicamba product is set to automatically expire on December 20, 2020. EPA is currently considering applications for registration of dicamba products for preemergence and postemergence use on DT soybean and cotton for the 2021 growing season.

This memorandum assesses the general benefits of preemergence and postemergence use of dicamba on DT soybean, as well as alternatives to postemergence use of dicamba on DT soybean, to inform the final registration decision. This assessment also presents information on the historical usage of dicamba in DT soybean, including data and information on the percentage of acreage treated, application timings, and target pests. This memorandum is one in a series that address the use of dicamba in DT cropping systems that are available in the docket. The usage, alternatives, and benefits of preemergence and postemergence dicamba in cotton are discussed in *Assessment of the Benefits of Dicamba Use in Genetically Modified, Dicamba Tolerant Cotton*

Production (Orlowski and Kells, 2020). The impact of potential controls for preemergence and postemergence dicamba in cotton and soybean are discussed in *Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to Users and Non-Users from Proposed Registrations (*Chism et al., 2020).

METHODOLOGY

BEAD qualitatively assesses the benefits of preemergence dicamba use in DT soybean and quantitively assesses the benefits and alternatives of postemergence dicamba used in DT soybean by comparing grower outcomes with the use dicamba in DT soybean to grower outcomes with the use of existing alternative herbicide control programs. The unit of analysis for this assessment is an acre of DT soybean that would likely be treated with dicamba. BEAD assesses the benefits of postemergence dicamba use in DT soybean in the largest Northern soybean production region (Corn Belt) and the largest Southern soybean production region (Mid-South). BEAD chose these regions to represent major soybean producing regions with different target weed species. Dicamba for postemergence use was initially registered in late 2016 and therefore limited data on dicamba usage are available for this comparison. Data on use of DT seed and dicamba use are available from 2017-2018; data on use of alternative herbicides are available from 2014-2018.

BEAD first identifies the primary weeds targeted by growers when using postemergence dicamba. Data for this purpose comes from state agricultural Extension services, primary peer-reviewed literature publications, and pesticide market research data, collected through annual surveys of growers conducted by a leading private research firm (Kynetec, Inc.). The surveys provide representative, statistically valid data with which to draw conclusions about grower use of herbicides and seed trait adoption. BEAD identifies alternative herbicide options using market research data as well as land grant university and Extension publications. Alternative herbicide control programs are identified using data from state agricultural Extension agencies combined with the professional judgment of BEAD agronomists and agricultural economists based on biological considerations (*e.g.*, similar or improved weed control, herbicide resistance management) and economic considerations (*e.g.*, lower costs, including non-monetary costs such as managerial effort). BEAD collected information on herbicide costs from pesticide market research data (Kynetec, 2019). BEAD collected data on the performance of alternative herbicides on important weed species for dicamba from published Extension weed control recommendations.

BEAD then considers differences in weed control costs per acre and/or revenue per acre in the context of grower income to characterize potential benefits of postemergence dicamba in soybean and/or impacts of restrictions on dicamba use. BEAD uses net operating revenue, defined as gross revenue per acre less operating costs per acre, as the measure of income. Data from the U.S. Department of Agriculture (USDA) Economic Research Service (ERS) are used to calculate average gross revenue per acre. Fixed costs, such as land rent, equipment depreciation, and overhead costs, although estimated by ERS, are not included because allocating these costs on a per-acre basis is complex due to the variation in farm size and diversity in farm production. Moreover, these fixed costs are often not included in crop budgets produced by other organizations. For consistency across use sites, BEAD relies on measures of net operating revenue, acknowledging that this overstates grower income per acre by not accounting for fixed costs and will underestimate the potential per-acre benefit of pesticide use. By assessing the benefits of dicamba on a per-acre basis, BEAD's conclusions about the benefits of dicamba are independent of BEAD's estimates of total dicamba usage and therefore are not impacted by over- or undercounting of dicamba usage.

BACKGROUND

Previous EPA Assessments of the Benefits of Registering Postemergence Dicamba

In 2016, BEAD assessed the benefits of dicamba intended for use in DT crops using registrant claims, and found that the main benefit of postemergence OTT dicamba was that it provided DT soybean and cotton growers with another active ingredient to manage difficult to control broadleaf weeds during the crop growing season, especially glyphosate-resistant weeds (Yourman and Chism, 2016).

The Agency again assessed the benefits of dicamba intended for use in DT crops production in 2018 (EPA, 2018d). The 2018 assessment found that the registration of postemergence dicamba provides growers with an additional active ingredient to manage problematic broadleaf weeds, especially for situations where herbicide-resistant populations of these weeds are known to occur. The 2018 assessment also found that the registration of postemergence dicamba provides a long-term benefit as a tool to delay the evolution of resistance in weed species to other herbicides when used as part of a season-long weed management program. Since the release of the 2018 assessment, dicamba-resistant Palmer amaranth has been confirmed in two states; see the section below titled "Dicamba Resistance in Dicamba Target Weeds." As dicamba resistance in target weed species is expected to spread, the benefits of dicamba in DT soybean will be lower than those assessed in 2018, although the decreased benefits will be concentrated in area where dicamba-resistant broadleaf weed species are established.

In 2019, EPA also assessed the benefits of another dicamba product, a pre-mix of dicamba and S-metolachlor (Tindall, 2019). EPA found no unique benefits to the product not discussed in the 2018 assessment.

Registrant Submission of Information Regarding the Benefits of Registering Postemergence Dicamba for Use on DT Soybean

In 2020 Bayer submitted a document supporting the registration of postemergence dicamba (Bayer, 2020). This document states that dicamba is useful as an additional mode of action to combat herbicide-resistant weeds. Bayer also suggests that, in the absence of postemergence dicamba growers who face herbicide-resistant weeds may be forced to use more expensive and less effective alternatives, which may decrease grower revenues and result in yield loss. The document also states that also states that various crop production practices, such as tillage, can be used as an alternative to herbicides for resistant weeds but may have a negative impact on the environment. The document also suggests that postemergence dicamba, when used as part of a soil residual and postemergence weed management program, can help mitigate the potential for the development of weed resistance to other herbicides. Bayer suggests that the absence of postemergence dicamba may result in overuse of remaining postemergence herbicide modes of action and thus may increase selection pressure in problematic weed species for resistance to these herbicides.

Letters Describing the Benefits of Postemergence Dicamba

While there was no public comment period for the 2018 or pending 2020 dicamba registration decisions, the Agency has received dozens of letters concerning the pending dicamba registrations for use with DT cotton and soybean. For a summary of comments and a list of commenters see Chism et al. (2020). Information from the submitted letters are incorporated, as appropriate, in this memo, the benefits memo for and soybean (Orlowski and Kells, 2020) and the impacts memo (Chism et al., 2020).

WEED MANAGEMENT IN SOYBEAN

Soybean is the second highest acreage crop in the U.S. following only corn. Soybeans are produced at latitudes from North Dakota to South Texas and from the Eastern Seaboard to the Rocky Mountains. Given the large geographic acreage where soybeans are grown, production conditions and practices can vary greatly in different parts of the country.

Across the U.S., soybean is a major rotational partner with corn but are also rotated with other cereal crops such as wheat and rice. Soybean are a leguminous crop, meaning that they fix nitrogen. Breakdown of soybean residue can release nitrogen which can be utilized by subsequent grain crops. In southern production regions, especially the Mississippi Delta, soybeans are often rotated with cotton, but continuous soybean production systems are commonplace as well.

Weeds compete with soybean for limited resources such as space, nutrients, moisture, and may serve as reservoirs or hosts for insect pests and/or pathogens. To effectively manage weeds in fields producing soybean, growers rely on several management tactics that can include tillage, cultivation, and herbicides. Hand weeding is usually not economically feasible for soybean and cultivation is rarely practiced due to crop row spacing, the relatively slow speed of cultivation operations compared to herbicide application, and soil erosion concerns. Herbicides allow growers to avoid many of these non-chemical management costs and allow for the utilization of conservation tillage. While herbicides are the primary means of weed control in soybean, growers must consider multiple factors (*e.g.*, timing, weed targets, and resistance management) when making herbicide selections.

The goal of a soybean herbicide program is to plant soybeans into weed-free conditions and maintain a weed-free period until the soybean reach canopy closure. Weeds can be removed prior to planting using conventional tillage practices or with non-selective herbicides as part of a burndown herbicide program. Depending on the weed species present and the weed pressure in the field, preemergence residual herbicides are used to control or suppress weeds during early-season soybean growth. Eventually, the residual activity of preemergence herbicides begins to decline and weeds emerge from the soil, requiring the postemergence herbicide application. A foliar-applied herbicide is likely necessary to remove emerged weeds. Another herbicide that had residual activity is usually applied with the foliar herbicide to control or suppress weeds until the soybean canopy closure occurs.

Before the development of herbicide-tolerant soybean, common post-emergence weed control herbicides in soybean included bentazon (WSSA Group 6), multiple ALS inhibitor herbicides (WSSA Group 2) including chlorimuron and imazethapyr, and acifluorfen (WSSA Group 14) (Rowe, 2018). However, after the introduction of glyphosate-resistant soybean seed in1995, glyphosate rapidly became the most widely used postemergence herbicide used in soybean (Fernandez-Cornejo, 2014; Rowe, 2018). Glyphosate's broad-spectrum control and ease of use resulted in glyphosate-tolerant soybean producers using repeated applications to control weeds. Repeated applications of a single herbicide to the same weed species, such as Palmer amaranth, selected for individuals within the population with resistance to glyphosate. These resistant biotypes rapidly became the dominant biotype in a field, rendering glyphosate ineffective as an herbicidal control measure for these species. As control with glyphosate failed, other classes of herbicide were used for postemergence control of glyphosate-resistant weeds. Eventually problematic weeds, such as Palmer amaranth, developed resistance to these herbicides as well, resulting in weed populations with resistance to multiple herbicide modes of action and necessitating the development of novel herbicide control measures. However, no new herbicide modes of action have been developed for use in soybean in over 30 years. In lieu of new modes of action, companies have focused on developing novel herbicide-tolerant soybean varieties that are tolerant to existing herbicides, like dicamba, that traditionally could not be applied postemergence to soybean (Heap and Duke, 2017).

CHEMICAL CHARACTERISTICS

Dicamba is an herbicide in the benzoic acid chemical family. The Weed Science Society of America (WSSA) has classified dicamba as a Group 4 synthetic auxin type herbicide. Dicamba is primarily used to control broadleaf weeds, where it mimics the function of endogenous auxin. Dicamba induces cell wall elongation and increases in RNA, DNA, and protein biosynthesis leading to uncontrolled cell division that eventually results in plant death. Dicamba also induces ethylene production in the plant which is thought to cause the leaf cupping and epinastic bending symptoms seen in susceptible plants exposed to dicamba. Dicamba is a systemic herbicide and uptake occurs primarily through foliage. Due to its systemic activity, dicamba is most effective when applied to actively growing weeds and control is best when applied to smaller weeds. Dicamba was first registered in the U.S. in 1967 and has been used in extensively in both crop and non-crop areas ever since (Shaner, 2014).

CROP PRODUCTION INFORMATION

Production statistics for soybean are shown in Table 1 based on United States Department of Agriculture (USDA) Economic Research Service (ERS) production regions (USDA ERS, 2000). Nationally, 84.8 million acres of soybean are harvested per year, on average, producing over four billion bushels (bu) of soybean valued at around $40 billion (Table 1). USDA ERS (2020c) describes soybean as the world's largest source of animal protein feed and the second largest source of vegetable oil. The United States is the world's leading soybean producer and second leading exporter, and soybeans comprise about 90% of the United States' oilseed production. Between 2014 and 2017, soybean production, processing, and use, including biodiesel and livestock feed, generated about $115.8 billion in economic activity, supporting the equivalent of 280,000 full-time jobs (LMC International Ltd., 2019).

Around 40% of production comes from the midwestern states of the Corn Belt with another third coming from the Northeast and Northern Plains (USDA NASS, 2020). Another major production region is the Mid-South, which encompasses the highly productive soybean growing area along the Mississippi River floodplain and delta. National soybean yields for 2014-2018 averaged about 49 bushels per acre. Average gross returns averaged $456 per acre nationally and vary between $345 per acre in the Southern Plains to $524 per acre in the Corn Belt, primarily due to differences in yield (Table 1). ERS statistics are inclusive of both non-DT and DT soybean in the years following the deregulation of DT soybean seed.

Table 1. Acreage, Production, and Value of Soybean, 2014-2018 Averages.

Region	Harvested Acreage	Production (1,000 bu)	Yield (bu/acre)	Total Value ($1,000)	Gross Revenue ($/acre)
Corn Belt [1]	32,300,000	1,801,000	56	16,907,000	$524
Mid-South [2]	13,800,000	664,000	48	6,376,000	$461
Northern Plains [3]	17,000,000	778,000	46	6,929,000	$396
Northeast [4]	12,700,000	607,000	48	5,534,000	$434
Southern Plains [5]	5,000,000	194,000	39	1,715,000	$345
Southern Seaboard [6]	4,000,000	153,000	38	1,427,000	$356
U.S. Total	84,800,000	4,197,000	49	38,688,000	$456

Source: USDA/NASS, 2020 (QuickStats). Numbers may not sum due to rounding.

1 Corn Belt: Illinois, Indiana, Iowa, Kentucky, Ohio, West Virginia.

2 Mid-South: Arkansas, Louisiana, Mississippi, Missouri, Tennessee.

3 Northern Plains: Nebraska, North Dakota, South Dakota.

4 Northeast: Michigan, Minnesota, New Jersey, New York, Pennsylvania, Wisconsin.

5 Southern Plains: Kansas, Oklahoma, Texas.

6 Southern Seaboard: Alabama, Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia.

DICAMBA-TOLERANT TRAIT ADOPTION

Dicamba-tolerant soybean was developed via genetic modification and was deregulated by the U.S. Department of Agriculture (USDA) in 2015 (Firko, 2015). DT soybean seed was available for purchase and use by soybean growers in 2016. However, dicamba for postemergence use was not registered by EPA until after the 2016 growing season (Housenger, 2016). Since DT seed was available in 2016, but postemergence dicamba was not registered for use, BEAD considered 2016 a transition year for trait adoption and not representative of years where dicamba was a postemergence control option. Therefore, to provide context for dicamba usage, BEAD examines usage of dicamba on soybean varieties prior to introduction of DT traited soybean (in 2014 and 2015) and after the registration of postemergence dicamba for use on DT soybean (in 2017 and 2018). BEAD does not have market data for the 2019 or 2020 growing seasons. Acres planted with different seed traits before the introduction of the DT trait (2014-2015) and after the introduction of the DT trait (2017-2018) are presented in Table 2.

Table 2. Annual Average Soybean Acres Planted by Seed Trait, 2014-2015 and 2017-2018

Variety	Acres Grown by Trait, 2014-2015	Percentage of Acres Grown by Trait, 2014-2015	Acres Grown by Trait, 2017-2018	Percentage of Acres Grown by Trait, 2017-2018
Conventional	3,690,000	4%	3,530,000	4%
Glyphosate Tolerant	76,100,000[1]	90%	40,700,000[1]	46%
Other Herbicide-tolerant	4,680,000[2]	6%	15,200,000[2]	17%
Dicamba-tolerant	0	-	29,900,000[3]	33%
U.S. Total Soybean Acres	84,400,000		89,400,000	

Source: Kynetec, 2019. Calculations subject to rounding.
1 Includes varieties with combined tolerance to glyphosate and sulfonylurea herbicides.
2 Includes varieties with combined tolerance to glufosinate and/or sulfonylurea herbicides.
3 Includes varieties with combined tolerance to dicamba, glyphosate, and sulfonylurea herbicides.
4 DT seed was available in 2016, but postemergence dicamba was not registered until after the 2016 growing season. 2016 was considered a transition year for DT soybean.

According to market research data (Kynetec, 2019), one third of soybeans planted in 2017-2018 were DT. The increase in DT soybeans is not as a result of acres planted with conventional (*i.e.*, non-genetically engineered) seeds being newly planted with DT seed; the increase in the number of acres planted with conventional soybean is similar across the time periods (Table 2). The increase in acres planted in the “Dicamba-Tolerant” category and the corresponding decrease in the “Glyphosate Tolerant” category does not mean growers are planting less soybeans with glyphosate tolerance; rather, the dicamba-tolerant trait was added to varieties already tolerant to glyphosate. Growers also switched from glyphosate tolerant varieties to varieties tolerant to other herbicides, primarily glufosinate. While one third of soybeans planted in 2017-2018 were DT (Kynetec, 2019), a substantial increase in DT planted acres was observed year-over-year.

The USDA Economic Research Service (ERS) also provides information on grower use of DT seed and of dicamba. In some states (i.e., Mississippi), DT soybean may account for nearly 80% of planted acres; however, nationally, ERS shows a 41% adoption rate which is similar to the adoption rate in the primary states producing soybean (e.g., Illinois, Indiana and Iowa) (USDA ERS, 2020b). Because DT soybean seed adoption appears to be increasing, but BEAD does not have market research data more recent than 2018, the estimates of DT soybean adoption in Table 2 may underestimate current adoption.

DICAMBA USAGE IN SOYBEAN PRODUCTION

Dicamba Use by Region

Tables 3a and 3b present usage of dicamba prior to introduction of DT traits (2014 and 2015) and after the registration of postemergence dicamba (2017 and 2018). Preemergence dicamba usage in 2017 and 2018 includes both formulations of dicamba intended to be used postemergence with DT crops and older formulations of dicamba intended only for preplant burndown use. In 2016 DT seed was available but postemergence dicamba was not registered. BEAD considers 2016 a transition year. Preemergence dicamba use was low (~2% of soybean acres treated) before the release of DT soybean (Kynetec, 2019), likely due to preplant restrictions required for use of older dicamba formulations on non-DT soybean (Table 3a). While remaining low compared to postemergence use in 2017-2018, preemergence use of dicamba increased significantly in many regions resulting in a four-fold (2% versus 8%) increase in preemergence use across the U.S. (Table 3c). This increase is may be the result of the elimination of the preplant restrictions on dicamba products intended for use on DT soybean (see the section "Benefits of Preemergence Dicamba in Dicamba-Tolerant Soybean").

Table 3a. Average Annual Preemergence Dicamba Usage in Soybeans Prior to Release of DT Soybeans, 2014-2015

Region [1]	Percent Crop Treated Preemergence [2]	Total Acres Treated [3]	Pounds (lbs AI) Applied	Average Application Rate (lb/acre)
Corn Belt	1%	390,000	96,000	0.25
Mid-South	6%	920,000	200,000	0.22
Northern Plains	<1%	56,000	11,000	0.19
Northeast	<1%	18,000	2,900	0.16
Southern Plains	11%	530,000	96,000	0.18
Southern Seaboard	4%	18,000	4,200	0.24
U.S. Total	2%	1,930,000	410,000	0.21

Source: Kynetec, 2019. Calculations subject to rounding.

1 See Table 1 for states in each region.

2 Proportion of acres treated at least once with dicamba.

3 Total acres treated accounts for acres treated multiple times. 1 application per acre annually on average.

Table 3b. Average Annual Dicamba Usage in Soybeans After Release of DT Soybeans, 2017-2018

Region [1]	Percent Crop Treated [2,3]	Total Acres Treated [4]	Pounds (lbs active ingredient)	Average Application Rate (lb/acre)
Corn Belt	20%	7,930,000	3,570,000	0.45
Mid-South	23%	4,720,000	2,150,000	0.46
Northern Plains	24%	5,220,000	2,300,000	0.44
Northeast	10%	1,540,000	730,000	0.47
Southern Plains	46%	3,810,000	1,520,000	0.40
Southern Seaboard	14%	620,000	270,000	0.43
U.S. Total	21%	23,830,000	10,540,000	0.44

Source: Kynetec, 2019. Calculations subject to rounding.

1 See Table 1 for states in each region.

2 Proportion of acres treated at least once with dicamba.

3 Dicamba usage in 2017 and 2018 prior to crop emergence includes both dicamba products registered for use on DT soybean and those registered for use on non-DT soybean.

4 Total acres treated accounts for acres treated multiple times – each application is counted separately.

Table 3c. Average Annual Dicamba Usage by Timing, 2017-2018

Region [1]	Percent Crop Treated Preemergence [2,3]	Percent Crop Treated Postemergence [2]	Percent of Acres Treated Receiving 2 Postemergence Applications[4]	Average Application Rate Pre-emergence (lb/acre)	Average Application Rate Post-emergence (lb/acre)
Corn Belt	5%	17%	6%	0.34	0.49
Mid-South	11%	18%	17%	0.40	0.49
Northern Plains	9%	18%	5%	0.35	0.48
Northeast	1%	10%	6%%	0.43	0.48
Southern Plains	29%	32%	8%	0.31	0.48
Southern Seaboard	4%	11%	1%	0.37	0.46
U.S. Total	8%	17%	8%	0.35	0.48

Source: Kynetec, 2019. Calculations subject to rounding.

1 See Table 1 for states in each region.

2 Proportion of acres treated at least once with dicamba.

3 Dicamba usage in 2017 and 2018 prior to crop emergence includes both dicamba products registered for use on DT soybean and those registered for use on non-DT soybean.

4 Among acres treated with dicamba after crop emergence, the percentage of acres treated twice with dicamba after crop emergence.

A substantial increase in pounds of dicamba applied annually was observed between 2017 and 2018 (Kynetec, 2019). This increase in usage of dicamba matches the increase in adoption of DT seed over the same period (see the section above, Dicamba-Tolerant Trait Adoption). Market research data on pesticide usage are not yet available to the EPA for 2019. Because BEAD does not have market research data more recent than 2018, the estimates in Table 3b may underestimate current dicamba usage.

Dicamba Use by Timing

Prior to the introduction of DT soybean, dicamba use on soybean was limited to preplant use. For non-DT soybean, the preplant restriction (minimum 14 days and 1 in. rainfall) still applies (BASF, 2020). However, for DT soybean, dicamba products intended for use on DT soybean may be applied up to crop emergence, as well as postemergence. The majority of dicamba, approximately 80% (measured in pounds of active ingredient) was applied to DT soybean postemergence (Kynetec, 2019).

Average dicamba use in soybeans increased from 411,000 pounds a.i. (active ingredient) annually in 2014-2015 to over 10.5 million pounds of AI annually in 2017-2018. Over 95% of the dicamba poundage was applied to dicamba-tolerant acres (Kynetec, 2019).

Nationally, approximately 8% of the acreage treated with dicamba postemergence are treated twice postemergence. The percentage of acreage receiving two postemergence applications varied across major production regions from 1% in the Southeast to 17% in the Mid-South (Table 3c).

The average dicamba application rate increased after the introduction of DT seed (Tables 3a, 3b). This is due to a higher application rate of dicamba being used postemergence as well as higher preemergence rates (Table 3c). The increase in preemergence rates can likely be explained by differing label instructions between dicamba products intended for use on DT soybean and those products intended for preplant use on non-DT soybean. Dicamba products intended for preplant use on non-DT soybean specify users to apply between 0.125 and 0.5 lbs ai/A for preplant burndown control while dicamba products intended for use on DT soybean direct users to apply the full labeled rate of 0.5 lbs ai/A for each preemergence application.

BENEFITS OF PREEMERGENCE DICAMBA IN DICAMBA-TOLERANT SOYBEANS

The primary focus of this document is the determination of benefits associated with registration of postemergence dicamba on DT soybean. BEAD recognizes that DT soybean also allows for changes in the preemergence use of these products. The main benefit of this change is increased flexibility of in the timing of preemergence dicamba in DT soybean. BEAD qualitatively discusses the benefits of this change in preemergence dicamba use below.

Dicamba products intended for preplant use in non-DT soybean have been labeled for use in soybean prior to planting as part of a fall or spring weed burndown program. Non-DT soybean are sensitive to dicamba, therefore labels for these products specified a preplanting restriction, requiring a specified number of days and amount of rainfall or irrigation water to be accumulated between dicamba application and soybean planting to avoid injury to emerging non-DT soybean seedlings. These planting restrictions vary by dicamba application rate and formulation, but generally range from 14 days to 30 days between application and soybean planting (BASF, 2020).

The lack of preplanting restrictions on dicamba products intended for use on DT soybean provide a significant benefit to producers, allowing them to include dicamba in their burndown program regardless of the planting schedule. Growers utilizing dicamba products intended for use on non-DT soybean may have to delay planting to comply with the dicamba preplant label restriction. Since soybean yield is highly correlated to planting date (Egli, 2017), delaying planting can negatively affect soybean yield and thus grower profitability. Since DT soybean are highly tolerant of dicamba there is no need for this preplant restriction on the dicamba products intended for use on DT soybean and dicamba can be applied at any time for burndown, preplant, preemergence, and postemergence. Registering these dicamba products for use on DT soybean would give growers flexibility to use dicamba for weed control at these timings and eliminate the threat of delayed planting due to preplant restrictions.

BENEFITS OF POSTEMERGENCE DICAMBA IN DICAMBA-TOLERANT SOYBEANS

Prior to the introduction of the DT in soybeans, dicamba could only be used as a preplant application. The primary unique value of the dicamba formulations EPA is now considering registering is their ability to be used postemergence in DT soybeans, and therefore the focus of this document is determination of the benefits of dicamba for postemergence weed control in DT soybean. This section of the document will discuss the weed species likely to be targeted by postemergence dicamba application in soybean, as well as alternative herbicide programs currently available to soybean growers to manage target weed species, including herbicide-tolerant weeds. This section will also discuss the quantitative benefits of registering postemergence dicamba in two major U.S. soybean production regions and discuss issues related to postemergence dicamba and herbicide resistance.

Target Weeds

Using market research data (Kynetec, 2019), BEAD examined regional postemergence dicamba usage (Table 4). In the Corn Belt, the weed species most commonly targeted by soybean growers in their use of postemergence dicamba were waterhemp and marestail. In the Mid-South, Southern Plains, and Southern Seaboard, the most common target weeds for postemergence dicamba application were *Amaranthus* species (Palmer amaranth and redroot pigweed). In the Northern Plains, most common target weeds for postemergence dicamba were kochia and waterhemp. In the Northeast, waterhemp and ragweed are the most common target for postemergence dicamba application. As many of the amaranth species (redroot pigweed, Palmer amaranth, waterhemp) have similar growth habits, plant morphology and the ability to hybridize, identifying the exact species is often difficult at the farm level. BEAD recognizes that the *Amaranthus* species in general are a major target pest for postemergence control in soybean weed management.

Table 4: Weeds Targeted with Postemergence Dicamba, Percent of Postemergence-Dicamba-Treated Acres, 2017-2018

Weed	Corn Belt	Mid-South	Northern Plains	Northeast	Southern Plains	Southern Seaboard
Amaranth species	71%	73%	51%	58%	93%	87%
Waterhemp	*61%*	*13%*	*30%*	*54%*	*16%*	*<5%*
Palmer Amaranth	*5%*	*26%*	*10%*	*<5%*	*33%*	*44%*
Redroot Pigweed	*6%*	*34%*	*10%*	*<5%*	*44%*	*44%*
Kochia	<5%	<5%	50%	<5%	<5%	<5%
Ragweed	15%	<5%	5%	42%	<5%	8%
Marestail	25%	13%	15%	10%	16%	11%

Source: Kynetec, 2019.
Percent is percentage of treatments that were targeted for each weed. Acres can be treated more than once or treated for multiple weeds therefore numbers may not sum to 100%.
Waterhemp includes common and tall waterhemp.
Ragweed includes common ragweed and giant ragweed.

The market survey data are supported by publicly available state agricultural Extension recommendations and survey information provided by the WSSA. In a 2019 survey of farmers and crop consultants conducted by the WSSA respondents identified waterhemp, marestail, Palmer amaranth, and giant ragweed as the top four most troublesome weeds in soybean. Troublesome weeds refer to those weeds that are most difficult to control regardless of herbicide use or seed technology (VanWychen, 2019). The weed control guide for Ohio, Indiana, and Illinois (Corn Belt) list Palmer amaranth, waterhemp, marestail, kochia, common ragweed and giant ragweed as target weeds for both preemergence and postemergence weed control programs in soybean (Loux et al., 2019). Similarly, the weed control guide for Arkansas (Mid-South) lists Palmer amaranth and giant ragweed and the weed control guide for Mississippi (Mid-South) lists Palmer amaranth, waterhemp and common ragweed as targets for soybean weed control programs (University of Arkansas, 2020; MSU, 2020). The North Dakota (Northern Plains) weed control guide lists Palmer amaranth, waterhemp, common ragweed, kochia and marestail as weed targets for soybean weed control programs (Ikley, 2020). While other weed species are listed as targets in these state Extension weed control guides, the target weeds in these guides align with the target weeds reported in the market research data.

Description of Major Herbicide-Resistant Target Broadleaf Weeds

When glyphosate resistant weeds were present in soybeans, Livingston et al. (2015) found a reduction of $ 22.50 or 14% of total returns per planted acres. The costs associated with controlling herbicide-resistant weeds was one of the main driving forces for the development of DT (and other herbicide-tolerant) soybean varieties.

All of these weed species (discussed below) have populations that have developed resistance to at least one mode of action and multiple populations that have developed resistance to multiple modes of action. For postemergence herbicidal control to be effective, all listed weed species need to be treated when small. This fact, coupled with the fast growth rate exhibited by these weed species, means that the timing window for control with postemergence herbicides is narrow, which has implications for the herbicide control programs discussed later in this document.

Palmer amaranth

The first herbicide-resistant Palmer amaranth (*Amaranthus palmeri*) population was reported in 1989 in South Carolina (Heap, 2020). In the U.S., there are over 60 Palmer amaranth populations with resistance to at least one herbicide within eight mechanisms of action (Heap, 2020). Weed scientists have indicated that dicamba is only effective on Palmer amaranth when they are at or below 2 to 4 inches tall (McGinty et al., 2018). Since Palmer amaranth can grow 2 to 3 inches per day (Sosnoskie et al., 2014), there is a narrow window when effective applications of dicamba can be made.

Waterhemp

The first herbicide-resistant waterhemp (*Amaranthus tuberculatus [=A. rudis]*) population was reported in 1993 in Iowa (Heap, 2020). In the U.S., there are currently over 50 waterhemp populations with resistance to at least one herbicide within seven mechanisms of action and in Illinois one population is resistant to five mechanisms of action (Heap, 2020). Waterhemp, as with Palmer amaranth, must be treated when the weeds are less than 4 inches tall. Since tall waterhemp can grow 1 to 1 ¼ inches per day (Take Action, 2018), there is a narrow window when effective applications of dicamba can be made. While there are no known populations of dicamba-resistant waterhemp there are populations in three states that exhibit reduced sensitivity to dicamba (Bradley, 2020).

Ragweed (Common and Giant)

The first herbicide-resistant common ragweed (*Ambrosia artemisiifolia*) population was reported in 1990 in Michigan and the first herbicide-resistant giant ragweed (*Ambrosia trifida*) population was reported in 1998 in Indiana (Heap, 2020). In the U.S., there are over 20 common ragweed populations with resistance to at least one herbicide within four different mechanisms of action and three populations with resistance to three mechanisms of action (Heap, 2020). In the U.S., there are 20 giant ragweed populations with resistance to at least one herbicide within two mechanisms of action and three populations with resistance to two mechanisms of action (Heap, 2020). Both common and giant ragweed have a narrow window when they should be treated because the weeds should be only four to six inches tall for effective control (Take Action, 2020a, Take Action, 2020b).

Kochia

The first herbicide-resistant Kochia (*Kochia scoparia*) population was reported in 1976 in Kansas (Heap, 2020). In the U.S., there are currently over 40 kochia populations with resistance to at least one herbicide within five different mechanisms of action groups and, as described in Kansas, one population is resistant to four mechanisms of action (Heap, 2020). Prior to the introduction of dicamba-tolerant soybean, multiple populations of with resistance to dicamba had already been identified in multiple states. Kochia has a narrow window for herbicide treatment as Kochia should be 2 to 4 inches tall for effective control (Take Action, 2020c).

Marestail

The first herbicide-resistant marestail (*Conyza canadensis*) was reported in Mississippi in 1994. Dozens of populations of this species have developed resistance to at least one mode of action and multiple populations have become resistant to multiple herbicide modes of action (Heap, 2020). Marestail has a unique growth habit where it initially grows as a rosette before it goes through a rapid stem elongation, known as bolting. To obtain optimal control of marestail, treatment is necessary when it is in the rosette stage prior to bolting (Take Action, 2020d).

Dicamba Resistance in Dicamba Target Weeds

Dicamba-resistant Palmer amaranth has been confirmed in two states (Tenessee and Kansas) and. state Extension weed scientists have reported decreased Palmer amaranth sensitivity to dicamba in at least five states (Peterson et al., 2019; Barber, 2020; Bradley, 2020; Culpepper, 2020; Steckel, 2020a; Steckel and Perkins, 2020). Multiple populations of kochia that are resistant to dicamba have been confirmed (prior to the introduction of DT soybean) as well. As dicamba-resistant weed populations are expected to spread, the benefits of dicamba in DT soybean will decrease over time, although the decreased benefits will be concentrated in area where dicamba-resistant broadleaf weed species are established. For instance, the University of Tennessee has reported reduced efficacy for Palmer amaranth control for dicamba and downgraded its Palmer amaranth herbicide rating for dicamba (Steckel, 2020b; Steckel, 2020c).

Available Herbicide Programs for Postemergence Weed Control

One of the main driving factors for the development and use of postemergence dicamba is the prevalence of highly competitive broadleaf weed species (described in the previous 'Target Weeds' section) that have developed resistance to many herbicide modes of action, such as glyphosate and ALS inhibitor herbicides, previously used for postemergence weed control in soybean cropping systems.

Given the propensity of certain weed species, such as Palmer amaranth and waterhemp, to develop resistance to multiple herbicide modes of action, the EPA published two Pesticide Registration Notices (EPA, 2017a; EPA, 2017b) that closely mirror WSSA guidelines to delay the development of herbicide resistance in weeds and thus preserve currently effective herbicides and herbicide-tolerant crop technologies. The most important and fundamental recommendation is for herbicide programs to utilize at least two effective modes of action per crop for all weeds, taking into account the modes of action that the target weeds have developed resistance to (Norsworthy et al., 2012).

BEAD consulted publicly available state agricultural Extension weed control guides to identify postemergence weed control programs that soybean producers could utilize to effectively control herbicide-resistant Palmer amaranth and/or waterhemp (*Amaranthus* spp.) (Table 5). BEAD also used these Extension weed control guides to identify a postemergence herbicide program utilizing dicamba. This postemergence dicamba program was compared to the currently available herbicide programs to identify the benefits of registering dicamba for postemergence use in soybean.

The three main Extension weed control guides utilized were the 2019 Weed Control Guide for Ohio, Indiana, and Illinois (Loux et al., 2019); the 2020 Weed Control Guidelines for Mississippi (MSU, 2020); and the 2020 Arkansas Recommended Chemicals for Weeds and Brush Control (University of Arkansas, 2020). These weed control guides were chosen because they represent weed control recommendations encompassing two majoring soybean producing regions (Corn Belt and Mid-South) and encompassing a range of target weed species. All three of these guides rate the control of specific target weed species by a certain chemical on a 1 to 10 scale, with 10 representing the highest level of control. BEAD considered herbicides currently available for postemergence herbicide programs and the postemergence dicamba program if the Extension weed control guides indicated the herbicide that would provide at least "8" in control rating, which represents 80% control, for Palmer amaranth and/or waterhemp. For some herbicides the weed control guides rated combinations of herbicides (*e.g.* glyphosate + dicamba; glufosinate + 2,4-D, etc.). These combined ratings were considered when developing the herbicide programs.

Since the focus of this part of the document is on the benefits of the registration of postemergence dicamba, BEAD also assumed that all existing weeds were removed prior to soybean planting by tillage or burndown herbicide programs. BEAD also assumed that preemergence herbicides containing at least two modes of action (*e.g.,* metribuzin + S-metolachlor) were applied after planting to provide residual control of problematic weeds prior to postemergence applications.

While market research data suggests that most growers (92%) who use dicamba after crop emergence only use one application of dicamba after crop emergence (Kynetec, 2019), previously registered dicamba products intended for use on DT soybean and currently registered Tavium allowed two postemergence applications (EPA, 2018a,b,c). Therefore, currently available herbicide programs and the Dicamba-Tolerant dicamba program presented here include two postemergence passes (applications) which would likely be necessary in areas with large infestations of problematic herbicide-resistant weeds (Table 5). However, if the first postemergence application provides adequate weed control until the soybean reaches canopy closure, the second postemergence application may not be needed. Therefore, these herbicide programs may overestimate grower costs for growers who do not make a second postemergence application.

Table 5: Available Postemergence Herbicide Programs and Dicamba Program for Postemergence Weed Control in Soybean

	Herbicide 1	Herbicide 2	Herbicide 3	Herbicide 4	WSSA herbicide modes of actions effective against herbicide-resistant *Amaranthus* spp.
Current Programs [1]					
Glyphosate-Tolerant					
Pass 1	glyphosate	fomesafen	S-metolachlor		Group 14[2], Group 15
Pass 2	lactofen	-	-		Group 14
Glufosinate-Tolerant					
Pass 1	glufosinate	fomesafen	S-metolachlor		Group 10, Group 14, Group 15
Pass 2	lactofen	clethodim	-		Group 14
2,4-D-Tolerant					
Pass 1	glufosinate	2,4-D	-	-	Group 4, Group 10
Pass 2	glyphosate	2,4-D	fomesafen	S-metolachlor	Group 4, Group 14, Group 15
Alternative Program					
Dicamba-Tolerant					
Pass 1	glyphosate	dicamba	S-metolachlor		Group 4, Group 15
Pass 2	glyphosate	dicamba	fomesafen		Group 4, Group 14

1 Programs based on 2019 Weed Control Guide for Ohio, Indiana, and Illinois, the 2020 Weed Control Guidelines for Mississippi, and the 2020 Arkansas Recommended Chemicals for Weeds and Brush Control.

2 Group 4: dicamba and 2,4-D; Group 10: glufosinate; Group 14: fomesafen and lactofen; Group 15: S-metolachlor

The following section describes each herbicide program scenario used in this assessment and presented in Table 5. The herbicide programs presented below requires the use of the seed that incorporates the appropriate herbicide-tolerance trait. The impact of seed traits on grower costs are discussed in the section "Uncertainties in Cost Comparison".

Glyphosate-Tolerant Program

This program is representative of a herbicide program used in glyphosate-only tolerant soybean before the development of new herbicide resistance traits (dicamba, 2,4-D). Glyphosate is included in this program to control emerged grasses and susceptible broadleaf weed species. In this program, the PPO inhibitor herbicides (fomesafen, lactofen) provide the postemergence control of herbicide-resistant *Amaranthus* spp., while S-metolachlor provides residual control of later emerging Amaranthus spp. S-metolachlor has limited efficacy on ragweed, kochia, and marestail so another residual herbicide, such as pyroxasulfone (WSSA Group 15), would need to be substituted in areas where these weeds are problematic.

Due to the recent reliance on PPO herbicides for postemergence control of problematic weeds, populations of weeds resistant to PPO herbicides exist across the U.S. Populations of Palmer amaranth resistant to fomesafen have been identified in Arkansas, Illinois, and Tennessee, populations of waterhemp resistant to fomesafen have been identified in Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, and Wisconsin, and populations of common ragweed resistant to PPO herbicides have been identified in Delaware, Maryland, Michigan, New Jersey, North Carolina, Ohio, and Virginia (Heap, 2020). In areas where PPO resistant broadleaf weeds are present, this program likely would not provide adequate control and an alternative herbicide control program would need to be used.

Glufosinate-Tolerant Program

The glufosinate-tolerant program is an effective and currently available herbicide program. Glufosinate is a non-selective contact herbicide that provides the postemergence control of herbicide-resistant *Amaranthus* spp. Like the other herbicides used for postemergence control of *Amaranthus* spp. (dicamba, 2,4-D, PPO herbicides), glufosinate needs to be applied to small *Amaranthus* spp. to achieve adequate postemergence control. Glufosinate may not provide adequate control of grass weeds, so clethodim (WSSA Group 1 herbicide exclusively for the control of grass weeds) has been included in Pass 2 (Table 5) for this program to remove any grass weeds not controlled by glufosinate. Fomesafen and S-metolachlor are included to provide residual control of later emerging Amaranthus spp. as well as other broadleaf and grass weed species. To date, there have been no confirmed cases of resistance to glufosinate documented in field crop sites in the U.S (Heap, 2020). However, Extension weed scientists in Arkansas have reported decreased sensitivity of Palmer amaranth to glufosinate (Barber, 2020).

2,4-D-Tolerant Program

The 2,4-D-tolerant program is relatively new in the U.S. The soybean varieties used in this program are resistant to 2,4-D, glyphosate, and glufosinate. Both 2,4-D and glufosinate provide postemergence control of herbicide-resistant *Amaranthus* spp. Similar to the other current herbicide programs, fomesafen and S-metolachlor have been included to provide residual control of later emerging *Amaranthus* spp. Because the soybean varieties used in this program are also resistant to glyphosate, glyphosate has been included in Pass 2 (Table 5) to control any emerged grasses and other weeds not controlled by earlier herbicide applications. To date there have been no confirmed cases of resistance to glufosinate documented in field crop sites in the U.S. However, populations of 2,4-D-resistant waterhemp have been confirmed in Nebraska and Illinois and populations of 2,4-D-resistant Palmer amaranth have been confirmed in Kansas (Heap, 2020).

Dicamba-Tolerant Program

In the dicamba-tolerant program, dicamba provides the postemergence control of herbicide-resistant *Amaranthus* spp. Similar to the other postemergence herbicide programs, fomesafen and S-metolachlor have been included in the program to provide residual control of later emerging *Amaranthus* spp. Glyphosate has been included for control on non-herbicide-resistant broadleaf and grass weeds. Some state Extension weed specialists recommend applying glyphosate separately from dicamba in order to reduce antagonism and improve control of grass weeds which would necessitate a third herbicide pass (Unglesbee, 2019; Pucci, 2020). As discussed above, populations of dicamba-resistant Palmer amaranth have been identified in Kansas and Tennessee and multiple states have reported populations of Palmer amaranth and waterhemp that exhibit reduced sensitivity to dicamba (Barber, 2020; Bradley, 2020; Steckel, 2020a).

Herbicide Resistance Issues in Alternative Programs
BEAD notes that both the 2,4-D-Tolerant Program and the Dicamba-Tolerant Program rely on synthetic auxin (WSSA Group 4) herbicides for postemergence control of emerged weeds. Previous research and observations have reported cross resistance in weed species to synthetic auxin herbicides (Peterson et al., 2019; Barber, 2020; Steckel, 2020a). Cross resistance occurs when a weed develops a trait that makes it resistant to one herbicide (such as dicamba) and that trait also confers resistance to other similar herbicides (such as 2,4-D). Given the threat of cross resistance, the development of weed populations resistant to dicamba could reduce the efficacy of 2,4-D based postemergence herbicide programs (and vice versa) reducing herbicide options available to producers and potentially reducing the benefits of registering dicamba for postemergence use in soybean (Peterson, et al., 2019; Barber, 2020; Steckel, 2020a).

Herbicide Control Based on Market Research Data
After the release of DT soybeans, growers had a new option to control for postemergence control of problematic weeds. To determine how growers might control weeds, including herbicide-resistant weeds, if dicamba is not registered for postemergence use, BEAD examined market research data (Kynetec, 2019) to see what growers that planted DT soybeans and used postemergence dicamba in 2017-2018 used for postemergence control in soybeans in 2014-2015 (Table 6). According to the data, glyphosate was the most commonly used postemergence herbicide used by these growers in soybean in 2014-2015. Other commonly used herbicides include fomesafen, S-metolachlor, and lactofen. It appears that users of postemergence dicamba in 2017-2018 primarily used glyphosate-tolerant soybean and PPO inhibitor herbicides (fomesafen, lactofen) for postemergence control in 2014-2015 (Table 6).

Table 6: Herbicides Most Commonly Used Postemergence in 2014-2015 by Growers Who Grew DT Soybeans and Used Dicamba Postemergence in 2017-2018.

Herbicide	Annual Acres Treated with Herbicide[1]	Percent of Acres Treated with Herbicide
Glyphosate	6,830,000	97%
Fomesafen	6,630,000	27%
S-Metolachlor	1,860,000	18%
Clethodim	1,220,000	9%
Lactofen	590,000	8%
Pyroxasulfone	510,000	7%
Acetochlor	390,000	6%
Fluthiacet-Methyl	360,000	5%
Chlorimuron	320,000	5%

Source: Kynetec, 2019. Data from 2014/2015. Acreage is reduced since not all growers who were surveyed using DT soybeans in 2017/2018 were also surveyed in 2014/2015.
1 Proportion of acres treated at least once with each herbicide.

BEAD also examined what herbicides growers who did not grow DT soybeans used in 2017-2018. Growers who did not grow DT soybeans most frequently applied glyphosate, with the second most commonly applied herbicide being glufosinate. Other commonly applied herbicides include fomesafen, clethodim, and S-metolachlor. These data indicate that growers who did not grow DT soybean in 2017-2018 used a glufosinate tolerant herbicide program or continued to use glyphosate tolerant soybean and relied on PPO herbicides for postemergence control of herbicide-resistant broadleaf weed control (Table 7).

Table 7: Herbicides Most Commonly Used Postemergence by Growers of Non-DT Soybeans in 2017-2018.

Herbicide	Annual Acres Treated with Herbicide[1]	Percent of Acres Treated with Herbicide
Glyphosate	36,720,000	68%
Glufosinate	14,590,000	27%
Fomesafen	13,410,000	25%
Clethodim	7,970,000	15%
S-Metolachlor	4,140,000	8%
Fluthiacet-Methyl	1,930,000	4%
Acetochlor	1,840,000	3%
Imazethapyr	1,460,000	3%
Pyroxasulfone	1,300,000	2%

Source: Kynetec, 2019. Acreage includes all soybean acres planted without the DT trait.
1 Proportion of acres treated at least once with each herbicide.

Postemergence 2,4-D usage does not appear in market research data in 2017-2018 because seed resistant to 2,4-D, glufosinate, and glyphosate (Enlist E3) only became available starting in the 2019 growing season.

Non-Herbicide Weed Control

Preplant conventional tillage can remove emerged problematic weeds before the crop is planted but does not affect weed emergence after the crop emerges. Post planting and postemergence mechanical cultivation is a potential option for control of problematic, herbicide-resistant weeds. However, in-crop cultivation is not able to achieve the same level of control as multiple herbicides and herbicide programs because it can only control weeds between rows and not the weeds within in the row of soybeans. Furthermore, in-crop cultivation is slower than applying herbicides with modern sprayer technology and may require more passes across the field, increasing costs for soybean growers. Also, in-row cultivation is not compatible with narrow row production systems that are utilized in many parts of the U.S. Given the high costs, relative ineffectiveness of cultivation, and soil conservation concerns BEAD is not considering non-herbicide programs in this document.

Quantitative Benefits of Using Postemergence Dicamba

To determine how growers would respond to the registration of postemergence dicamba, BEAD compares grower revenues using currently available weed control programs to the Dicamba-Tolerant Program. BEAD determines the costs of these herbicide programs based on market research data from 2017-2018 (Kynetec, 2019). As 2,4-D was not used after crop emergence in soybeans in the United States in the 2017-2018 period, Kynetec (2019) cost data are not available; therefore, BEAD determines the price of postemergence 2,4-D (Enlist One) based on state agricultural Extension production guides (SDSU, 2020; KSU, 2020).

BEAD places the changes in herbicide costs into the context of grower production using 2018 soybean production budgets from the Economic Research Service (2020a). In the Northern regions, postemergence dicamba would likely be used primarily to target waterhemp, while in the Southern regions, postemergence dicamba would likely be used primarily to target Palmer amaranth. For this reason, BEAD analyzes the benefits of registering postemergence dicamba separately for the largest Northern region (the Corn Belt) and the largest Southern region (the Mid-South). Table 8 shows the cost of the relevant alternative herbicides, broken down by region (Corn Belt versus Mid-South) according to market research data (Kynetec, 2019) and Extension guides (SDSU, 2020; KSU, 2020). The cost impacts resulting from registering postemergence dicamba, as calculated below, may be larger as a percentage of grower revenue in regions with lower yield.

Table 8: Average Per-Acre Per-Application Cost ($/A) of Dicamba and Alternative Postemergence Herbicides by Region, 2017-2018

Chemical	Corn Belt	Mid-South
Dicamba	$10	$9
Glyphosate	$5	$5
Glufosinate	$15	$15
2,4-D (Enlist One)	$11[1]	$11[2]
S-metolachlor	$7	$6
Fomesafen	$7	$6
Clethodim	$5	$6
Lactofen	$11	$12

Sources: Price data from Kynetec (2019), SDSU (2020), and KSU (2020). Prices based on postemergence use and average use rates.
1 Price of 2,4-D in the Corn Belt comes from South Dakota Extension recommendations and assumes 1.75 pints per acre. Price may differ from what growers actually pay.
2 Price of 2,4-D in the Mid-South comes from Kansas Extension recommendations and assumes 1.75 pints per acre. Price may differ from what growers actually pay.

<u>Postemergence Dicamba in the Corn Belt</u>

The largest Northern soybean production region is the Corn Belt (Table 1). BEAD uses the ERS budget for the Heartland region to compare production costs. Herbicide costs are based on market research data and extension recommendations (Table 8). BEAD calculates that the Dicamba-Tolerant Program may have herbicide costs of $44/A, including a first pass with glyphosate ($5/A), dicamba ($10/A), and s-metolachlor ($7/A), and a second pass with glyphosate ($5/A), dicamba ($10/A), and fomesafen ($7/A) (Table 5). This herbicide cost is represented in the Dicamba-Tolerant Program column of Table 9 below.

Growers considering using postemergence dicamba may be currently using one of three alternative herbicide programs. Switching from 2,4-D-Tolerant Program to the Dicamba-Tolerant Program, growers would see a decrease in herbicide costs of $12/A, from $56/A to $44/A (Table 9). Switching from the Glyphosate-Tolerant Program to the Dicamba-Tolerant Program, growers would see a $14/A increase in herbicide costs, from $30/A to $44/A. And switching from the Glufosinate-Tolerant Program to the Dicamba-Tolerant Program, growers would see little change in costs – a $1/A decrease in herbicide costs, from $45/A to $44/A.

Table 9: Comparing Per-Acre Impacts on Grower Costs and Net Operating Revenues from Switching to Postemergence Dicamba Programs in the Corn Belt

	Dicamba-Tolerant Program[4]	2,4-D Tolerant Program[5]	Glyphosate Tolerant Program[6]	Glufosinate Tolerant Program[7]
Gross Revenue	$524	$524	$524	$524
Postemergence Herbicide Costs	$44	$56	$30	$45
Other Operating Costs[1,2]	$89	$89	$89	$89
Seed Cost[3]	$57	$57	$57	$57
Net Operating Revenue	$334	$322	$348	$333
Change in Net Operating Revenue Switching to Postemergence Dicamba		+$12	-$14	+$1
Percent Change in Net Operating Revenue Switching to Postemergence Dicamba		+3.7%	-4%	+0.3%

Source: Budgets from ERS (2020a).

1 Other operating costs include preemergence herbicides, fertilizer, custom services, fuel, lube, electricity, repairs, hired labor, and interest on operating capital. BEAD includes labor in operating costs even though ERS includes labor in overhead. BEAD excludes family labor.

2 Preemergence herbicides are assumed to be one trip with paraquat and one trip with s-metolachlor and metribuzin. The cost of this preemergence program is calculated to be $20 per acre in the Corn Belt (Kynetec, 2019).

3 Seed costs are regional average over conventional and GM seeds – budgets do not account for variation in seed costs between herbicide-tolerance traits, or variation in seed costs within herbicide-tolerance traits.

4 Postemergence herbicides include a first pass with glyphosate, dicamba, and s-metolachlor, and a second pass with glyphosate, dicamba, and fomesafen. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

5 Postemergence herbicides include a first pass with glufosinate and 2,4-D, and a second pass with glyphosate, 2,4-D, fomesafen, and s-metolachlor. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

6 Postemergence herbicides include a first pass with glyphosate, fomesafen, and s-metolachlor, and a second pass with lactofen. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

7 Postemergence herbicides include a first pass with glufosinate, fomesafen, and s-metolachlor, and a second pass with lactofen and clethodim. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

Postemergence Dicamba in the Mid-South

The largest Southern soybean production region is the Mid-South (Table 1). BEAD uses the ERS budget for the Mississippi Portal region to compare production costs, as the two regions cover a similar area. Herbicide costs are based on market research data and extension recommendations (Table 8). BEAD calculates that the Dicamba-Tolerant Program may have herbicide costs of $40/A, including a first pass with glyphosate ($5/A), dicamba ($9/A), and s-metolachlor ($6/A), and a second pass with glyphosate ($5/A), dicamba ($9/A), and fomesafen ($6/A) (Table 5). This herbicide cost is represented in the Dicamba-Tolerant Program column of Table 10 below.

Growers considering using postemergence dicamba may be currently using one of three alternative herbicide programs. Switching from the 2,4-D-Tolerant Program to the Dicamba-Tolerant Program, growers would see a decrease in herbicide costs of $14/A, from $54/A to $40/A, equivalent to a 7.3% increase in net operating revenue (Table 10). Switching from the Glyphosate-Tolerant Program to the Dicamba-Tolerant Program, growers would see an $11/A increase in herbicide costs, from $29/A to $40/A, equivalent to a 5.1% decrease in net operating revenue. And switching from the Glufosinate-Tolerant Program to the Dicamba-Tolerant Program, growers would see a $5/A decrease in herbicide costs, from $45/A to $40/A, equivalent to a 2.5% increase in net operating revenue.

Table 10: Comparing Per-Acre Impacts on Grower Costs and Net Operating Revenues from Switching to Postemergence Dicamba Programs in the Mid-South

	Dicamba-Tolerant Program[4]	2,4-D Tolerant Program[5]	Glyphosate Tolerant Program[6]	Glufosinate Tolerant Program[7]
Gross Revenue	$461	$461	$461	$461
Postemergence Herbicide Costs	$40	$54	$29	$45
Other Operating Costs[1,2]	$153	$153	$153	$153
Seed Cost[3]	$63	$63	$63	$63
Net Operating Revenue	$205	$191	$216	$200
Change in Net Operating Revenue Switching to Postemergence Dicamba		+$14	-$11	+$5
Percent Change in Net Operating Revenue Switching to Postemergence Dicamba		+7.3%	-5.1%	+2.5%

Source: Budgets from ERS (2020a).

1 Other operating costs include preemergence herbicides, fertilizer, custom services, fuel, lube, electricity, repairs, hired labor, and interest on operating capital. BEAD includes labor in operating costs even though ERS includes labor in overhead. BEAD excludes family labor.
2 Preemergence herbicides are assumed to be one trip with paraquat and one trip with s-metolachlor and metribuzin. The cost of this preemergence program is calculated to be $18 per acre in the Mid-South (Kynetec, 2019).
3 Seed costs are regional average over conventional and GM seeds – budgets do not account for differences in seed costs by herbicide-tolerance traits.
4 Postemergence herbicides include a first pass with glyphosate, dicamba, and s-metolachlor, and a second pass with glyphosate, dicamba, and fomesafen. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.
5 Postemergence herbicides include a first pass with glufosinate and 2,4-D, and a second pass with glyphosate, 2,4-D, fomesafen, and s-metolachlor. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.
6 Postemergence herbicides include a first pass with glyphosate, fomesafen, and s-metolachlor, and a second pass with lactofen. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

7 Postemergence herbicides include a first pass with glufosinate, fomesafen, and s-metolachlor, and a second pass with lactofen and clethodim. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

Dicamba Resistance and Herbicide Costs

As discussed in the section "Dicamba Resistance in Dicamba Target Weeds" above, Palmer amaranth that is resistant to dicamba has been confirmed in two states (Peterson et al., 2019; Steckel, 2020a) and there have been multiple reports of reduced sensitivity of *Amaranthus* spp. to dicamba (Barber, 2020; Culpepper, 2020). In Tennessee, where dicamba-resistant Palmer amaranth has been confirmed, state Extension weed specialists recommend that glufosinate be applied as a third pass following the first two dicamba applications (Steckel, 2020d). Soybeans with combined tolerance to dicamba, glyphosate, and glufosinate were accepted for import by the European Union on September 29, 2020, meaning that soybean seed with tolerance to these three herbicides will likely be available in 2021. DT soybean growers encountering dicamba resistance will likely need to utilize this third pass with glufosinate to achieve satisfactory weed control. Adding this third pass with glufosinate to the Dicamba-Tolerant Program in soybeans increases postemergence herbicide costs by an additional $15/A in the Corn Belt (Table 8), from $44/A (Table 9) to $59/A. Adding this third pass increases postemergence herbicide costs by an additional $15/A in the Mid-South (Table 8), from $40/A (Table 10) to $55/A. Growers would also have increased operating costs from the equipment, fuel, and labor required to make a third trip through the field. As a result, the Dicamba-Tolerant program may be more expensive for growers facing dicamba-resistant weeds than alternative herbicide programs.

Antagonism Between Dicamba and Glyphosate

Dicamba has been shown to antagonize the activity of glyphosate on grass weeds. Some state Extension weed specialists recommend applying glyphosate separately from dicamba in order to reduce antagonism and improve control of grass weeds, which would necessitate a third herbicide pass (Unglesbee, 2019; Pucci, 2020). Growers facing grass pressure who choose to apply glyphosate separately would have increased operating costs from the equipment, fuel, and labor required to make a third trip through the field, though their herbicide costs would not increase. As a result, the Dicamba-Tolerant program may be more expensive for growers facing grass weeds than alternative herbicide programs which do not have antagonism concerns. Growers who are already making a third trip to apply glufosinate for dicamba-resistant weeds would be able to apply glyphosate with glufosinate on the third trip (University of Arkansas, 2020).

Uncertainties in Cost Comparison

In order to apply postemergence glyphosate, glufosinate, dicamba, or 2,4-D growers must purchase seed with the appropriate herbicide-tolerant trait, though seed can be tolerant to multiple herbicides. However, BEAD recognizes that there are multiple factors that producers consider when selecting a soybean variety to plant besides herbicide tolerance traits. These factors and characteristics can include yield performance, disease resistance, brand loyalty, suitability for climate, and availability in addition to herbicide tolerance. Further, grower seed costs may be strongly influenced by seller incentive programs and rebates companies may offer growers purchasing seed and herbicides. Variation in U.S. seed prices can be large – according to the U.S. Seed Price Transparency Report in 2019, in-state price differences of $40/bag for the same brand of soybeans are common (FBN, 2019). Differences in seed costs and available rebates may be large enough to drive grower decision-making with regards to herbicide choice. Since all of these factors contribute to the cost of producing a specific soybean variety, BEAD is unable to assess the overall impact of selecting herbicide tolerance programs to grower costs and revenue beyond that described above (Tables 9 and 10).

Resistance Management

The registration of dicamba for preemergence and postemergence control of herbicide-resistant broadleaf weeds can be beneficial for herbicide resistance management if used properly. As stated earlier in this document, a key strategy for delaying herbicide resistance in weeds is to utilize at least two effective modes of action in a weed control program. If postemergence dicamba is applied with other effective modes of action (*e.g.,* PPO inhibitor herbicides) this can help delay herbicide resistance in both classes of herbicides. Future stacking of the dicamba tolerance seed trait with other herbicide-tolerant traits, like glufosinate, in soybean varieties could also help to manage the development of herbicide-resistant weeds, as soybean growers would be able to utilize multiple herbicide modes of action on problematic species. However, soybean growers currently have the option to use 2,4-D to control problematic herbicide-resistant weeds in 2,4-D resistant soybeans. Since dicamba and 2,4-D have the same herbicidal mode of action (WSSA Group 4) the registration of dicamba for use on DT soybean does not necessarily give growers a new mode of action compared to currently available alternatives, but may give another mode of action to growers unable or unwilling to use 2,4-D-resistant soybeans. Multiple dicamba resistant populations of herbicide-resistant Palmer amaranth have been confirmed and state Extension weed scientists have reported resistance to dicamba in Palmer amaranth also confers resistance to 2,4-D (Peterson et al., 2019; Barber, 2020; Steckel, 2020a). As dicamba resistance in problematic weed species, like Palmer amaranth, becomes more widespread the usefulness of both 2,4-D and dicamba as tools for herbicide-resistance management will decline. However, it is difficult to predict exactly where new populations of dicamba-resistant weeds will occur, meaning that impacts to individual growers will vary by location, proximity to existing dicamba-resistant populations, current and past crop production practices, and experience dealing with herbicide-resistant weed species.

CONCLUSIONS

This document describes the benefits of registering dicamba for preemergence and postemergence use on dicamba-tolerant (DT) soybean. Soybean is the second highest acreage crop in the United States, with $38.7 billion worth of soybean grown each year on 84.8 million acres. In 2017 and 2018, growers used dicamba on 8% of all U.S. soybean acres (DT and non-DT) prior to crop emergence and on 17% of all U.S. soybean acres after crop emergence. Postemergence dicamba is primarily used to target herbicide-resistant Palmer amaranth, waterhemp, kochia, ragweed, and marestail but is effective at controlling a range of broadleaf weed species.

The dicamba tolerant system was created to address weed populations with resistance to glyphosate (Weed Science Society of America [WSSA] Group 9 herbicide), ALS (acetolactate synthase) inhibitor herbicides (WSSA Group 2) and PPO (protoporphyrinogen oxidase) inhibitor herbicides (WSSA group 14). The registration of dicamba in DT soybean would give growers additional flexibility in choosing varieties for managing herbicide-resistant weed populations, thereby prolonging the effectiveness of currently available control options for herbicide-resistant weed species. For areas where dicamba products cannot be used on DT soybean, there are effective alternative weed control programs currently available for the control of problematic broadleaf weeds in soybean. However, the number of postemergence herbicide options is very limited; therefore, many soybean growers can benefit from the registration of dicamba for use in DT soybean.

In addition to postemergence application, dicamba in DT soybean has utility prior to crop emergence. Dicamba products intended for use on non-DT soybean include a preplant restriction of a specified number of days and amount of rainfall to between dicamba application and planting to avoid soybean injury from dicamba. Since DT soybean are highly tolerant of dicamba, dicamba products intended for use on DT soybean do not include preplant restrictions increasing the flexibility for preemergence dicamba use. This increased flexibility of preemergence use of dicamba on DT soybean is another benefit of the registration of these dicamba products.

Relative to some herbicide programs (*e.g.,* a 2,4-D based program) postemergence dicamba may reduce grower costs by $12-$14 per acre, which may account for 4%-7% of grower net operating revenue, depending on the region. Seed costs and rebates offered by seed and chemical manufacturers can vary widely and affect the overall cost of the herbicide program.

In addition, the further development of dicamba-resistant weed populations would reduce the benefits of this technology in areas where dicamba resistant populations emerge. For example, additional herbicide applications may be necessary to achieve adequate weed control where species are experiencing decreased susceptibility to dicamba, increasing the cost of the postemergence dicamba program relative to alternative herbicide programs. Dicamba-resistant Palmer amaranth have been confirmed in two states. Furthermore, antagonism between glyphosate and antagonism may require growers facing pressure from grass weeds to make additional passes through the field. Risk control measures, discussed in *Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to Users and Non-Users from Proposed Registrations* (Chism et al., 2020), may also impinge on the benefits of dicamba, depending on the measure itself.

Overall, BEAD concludes that the registration of dicamba for preemergence and postemergence use in DT soybean gives many growers increased flexibility in their choice of seed varieties. Growers using DT seed have the option to use dicamba as a cost-effective way to control problematic herbicide-resistant broadleaf weed species, and as an additional tool to delay the further development of herbicide resistance.

REFERENCES

Barber, T. 2020. Recent Pigweeds Escapes are Troubling. Arkansas Row Crops Blog. http://www.arkansas-crops.com/2020/07/22/pigweed-escapes-troubling/

BASF. 2020. Specimen Label for Clarity® Herbicide. EPA Reg. No. 7969-137. Available at: http://www.cdms.net/ldat/ld797012.pdf

Bayer, 2020. Summary of Submissions: Support for Registration of XtendiMax®.

Bradley, K. 2020. Personal communication on September 3, 2020.

Chism, B., Becker, J., Tindall, K., Orlowski, J., Kells, B., Wyatt, T.J. 2020. Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to Users and Non-Users from Proposed Registrations. U.S. Environmental Protection Agency.

Culpepper, S. 2020. Dicamba-Resistant Pigweed? Not Yet But Troubling Signs Surface. Accessed on September 1, 2020 at https://agfaxweedsolutions.com/2020/04/14/dicamba-resistant-pigweed-not-yet-but-troubling-signs-surface/

Egli, D. 2017. Seed Biology and Yield of Grain Crops 2nd edition. Centre for Agriculture and Biosciences International.

FBN (Farmers Business Network). 2019. FBN Report: U.S. Seed Price Transparency 2019. Accessed 09/2020. https://emergence.fbn.com/resources/2019-us-seed-price-transparency-report

Fernandez-Cornejo, J., S. Wechsler, M. Livingston, and L. Mitchell. 2014. Genetically Engineered Crops in the United States. United States Department of Agriculture Economic Research Service. Report number 162. https://www.ers.usda.gov/webdocs/publications/45179/43668_err162.pdf?v=719.3

Firko, M.J. 2015. Determination of Nonregulated Status for Monsanto Company MON 87708 Soybean. United States Department of Agriculture. Animal and Plant Health Inspection Service. https://www.aphis.usda.gov/brs/aphisdocs/10_18801p_det.pdf

Heap, I. 2020. The International Herbicide-Resistant Weed Database. Online. Monday, August 10, 2020. Available www.weedscience.org

Heap, I. and S.O. Duke. 2017. Overview of glyphosate-resistant weeds worldwide. Pest Management Science: https://doi.org/10.1002/ps.4760

Housenger, J.E. 2016. Final Registration of Dicamba on Dicamba-Tolerant Cotton and Soybean. United States Environmental Protection Agency. EPA-HQ-OPP-2016-0187-0959 https://www.regulations.gov/document?D=EPA-HQ-OPP-2016-0187-0959

Ikley, J. (ed). 2020. North Dakota Weed Control Guide. North Dakota State University. https://www.ag.ndsu.edu/publications/crops/north-dakota-weed-control-guide/w253-20_-final-weed-guide-2020.pdf

Kansas State University (KSU) Research and Extension. 2020. 2020 Chemical Weed Control for Field Crop, Pastures, Rangeland and Noncropland.

Kynetec USA, Inc. 2019. The AgroTrak Study, Database Subset: 2014-2018. Market research data collected and sold by a private firm. Data collected on pesticide use for about 60 crops by annual surveys of agricultural users in the continental United States. Survey methodology provides statistically valid results, typically at the state level.

Livingston, M., J. Fernandez-Cornejo, J. Unger, C. Osteen, D. Schimmelpfennig, T. Park, and D. Lambert. 2015.. The Economics of glyphosate resistance management in corn and soybean production, ERR-184. US Department of Agriculture, Economic Research Service. April 2015.

LMC International Ltd. 2019. The Economic Impact of U.S. Soybeans and End Products on the U.S. Economy, Report for the United Soybean Board and National Oilseed Processors Association, November. Available at http://www.nopa.org/wp-content/uploads/2020/03/LMC_U.S.-Soy-Economic-Impact-Study-for-USB_FINAL-31320.pdf. Accessed October 2020.

Loux, M.M., D. Doohan, A.F. Dobbels, B. Reed, W.G. Johnson, B.G. Young, J. Iklley, and A. Hager. 2019. 2019 Weed Control Guide for Ohio, Indiana, and Illinois. Ohio State University Extension. https://cpb-us-w2.wpmucdn.com/u.osu.edu/dist/7/3461/files/2018/12/2019-Weed-Guide-2018-1214-accessible-1gnip2o.pdf

McGinty, J., S. Nolte, P. Dotray, M. Bagavathiannan, and G. Morgan. 2018. Application Timing is Critical with Auxin Herbicides. Texas Crop Newsletter. Texas A&M Agrilife Extension. https://agrilife.org/texasrowcrops/2018/03/09/application-timing-is-critical-with-auxin-herbicides/

Mississippi State University (MSU). 2020. 2020 Weed Control Guidelines for Mississippi. Mississippi State University Extension. http://extension.msstate.edu/sites/default/files/publications/publications/P1532_web.pdf

Orlowski, J. and B. Kells. 2020. Assessment of the Benefits of Dicamba Use in Genetically Modified, Dicamba Tolerant Cotton Production. U.S. Environmental Protection Agency.

Pucci, J. 2020. More dicamba sprayed but weed control lags. CropLife News 2/24/2020. Accessed online on September 9, 2020 at https://www.croplife.com/dicamba/xtend-dicamba-resistance/

Peterson, D., M. Jugulam, C. Shyam, and E. Borgato. 2019. Palmer amaranth resistance to 2,4-D and dicamba confirmed in Kansas. Kansas State Agronomy eUpdates March 1,

2019. Accessed online on August 20, 2020 at https://webapp.agron.ksu.edu/agr_social/eu_article.throck?article_id=2110

Rowe, A. 2018. Evolution of soybean weed management in the United States. Iowa State University.https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1060&context=creativecomponents

Shaner, D.(ed). 2014. Herbicide Handbook. Weed Science Society of America

SDSU (South Dakota State University Extension). 2020. 2020 South Dakota Pest Management Guide – Soybeans, A guide to managing weeds, insects, and diseases. Available at https://extension.sdstate.edu/sites/default/files/2020-01/P-00010.pdf

Sosnoskie, L.M., T.M. Webster, S. Culpepper. 2014. The Biology and Ecology of Palmer Amaranth: Implications for Control. University of Georgia. Accessed on September 4, 2018 at http://extension.uga.edu/publications/detail.html?number=C1000&title=The%20Biology%20and%20Ecology%20of%20Palmer%20Amaranth:%20Implications%20for%20Control

Steckel, L. 2020a. Dicamba-resistant Palmer amaranth in Tennessee: Stewardship even more important. July 7, 2020. Accessed online on August 20, 2020 at https://news.utcrops.com/2020/07/dicamba-resistant-palmer-amaranth-in-tennessee-stewardship-even-more-important/

Steckel, L.(ed.) 2020b. 2020 Weed Control Manual for Tennessee. University of Tennessee Extension Institute of Agriculture. https://extension.tennessee.edu/publications/Documents/PB1580.pdf

Steckel, L. 2020c, personal communication in email addressed to M. Hathaway, K. Tindall and D. Kenny, dated 26 April 2020

Steckel, L. 2020d. Strategies to address Palmer amaranth, junglerice and goosegrass Escapes from Follow-up Applications in Xtend and Enlist Crops. July 7, 2020. Accessed online on September 30, 2020 at https://news.utcrops.com/2020/07/strategies-to-address-palmer-amaranth-junglerice-and-goosegrass-escapes-from-follow-up-applications-in-xtend-and-enlist-crops/#more-19506

Steckel, L. and C. Perkins. 2020. Concerns About Poor Palmer Amaranth Control with Dicamba. June 30th, 2020. Accessed online on June 30th, 2020. https://news.utcrops.com/2020/06/concerns-about-poor-palmer-amaranth-control-with-dicamba/

Take Action. 2018. Waterhemp management in soybeans. Accessed online on September 1, 2020 at https://weedscience.missouri.edu/publications/50737_3_TA_FactSheet_Waterhemp.pdf

Take Action. 2020a. Common Ragweed. Accessed online on September 9, 2020 at https://iwilltakeaction.com/weed/common-ragweed

Take Action. 2020b. Management of Herbicide- Resistant Giant Ragweed. Accessed online on September 9, 2020 at https://iwilltakeaction.com/uploads/files/20200701-factsheet-giantragweed-usdadraft.pdf

Take Action. 2020c. Kochia management in soybeans. Accessed online on September 9, 2020 at https://iwilltakeaction.com/weed/kochia

Take Action. 2020d. Horseweed (Marestail). Accessed online September 18, 2020 at https://iwilltakeaction.com/weed/horseweed

Tindall, K. 2019. Review of Benefits and a Resistant Management Plant for a New Premix Herbicide Product, Dicamba (diglycolamine salt) + s-Metolachlor, for Use on Dicamba-Tolerant Cotton and Soybean (PC# 0128931 and 108800, DP# 450536 & 450508).

Unglesbee, E. 2019. Dicamba weed control concerns. Progressive Farmer. 8/30/2019. Accessed online on September 9, 2020 at https://www.dtnpf.com/agriculture/web/ag/crops/article/2019/08/30/possible-dicamba-resistance-cropping

University of Arkansas. 2020. MP 44 Recommended Chemicals for Weed and Brush Control. University of Arkansas System Cooperative Extension Service. https://www.uaex.edu/publications/MP-44.aspx

U.S. Court of Appeals for the Ninth Circuit. 2020. National Family Farm Coalition, Center for Food Safety; Center for Biological Diversity; Pesticide Action Network North America versus U.S. Environmental Protection Agency. Case 19-70115, June 3, 2020.

USDA ERS (United States Department of Agriculture, Economic Research Service). 2000. Farm Resource Regions. Agricultural Information Bulletin Number 760. Economic Research Service, U.S. Department of Agriculture. Accessed 04/2020. www.ers.usda.gov/webdocs/publications/42298/32489_aib-760_002.pdf?v=0. 1/2020.

USDA ERS (United States Department of Agriculture, Economic Research Service). 2020a. Commodity Costs and Returns. 2018 Recent Costs and Returns for Soybeans (Base Survey 2012). Economic Research Service, U.S. Department of Agriculture. Accessed 04/2020. https://www.ers.usda.gov/data-products/commodity-costs-and-returns/commodity-costs-and-returns/#Historical%20Costs%20and%20Returns:%20Soybeans.

USDA ERS (United States Department of Agriculture, Economic Research Service), 2020b. Special tabulation, based on the Agricultural Resources Management Survey: Crop Production Practices data. Compiled by Dodson, Laura.

USDA-ERS. 2020c. Soybean and oil crops. Accesses on Oct 24, 2020 at: https://www.ers.usda.gov/topics/crops/soybeans-oil-crops/#:~:text=Processed%20soybeans%20are%20the%20world's,and%20the%20second%2Dleading%20exporter.

USDA/NASS. 2020. Quick Stats, searchable database. Query for acreage, production, and value, by state, 2014-2018. Available at www.nass.usda.gov/Data_and_Statistics/index.php. Accessed March 2020.

US Environmental Protection Agency (EPA). 2017a. PRN 2017-1, Guidance for Pesticide Registrants on Pesticide Resistance Management Labeling

US Environmental Protection Agency (EPA). 2017b. PRN 2017-2, Guidance for Herbicide- Resistance Management, Labeling, Education, Training, and Stewardship. Guidance for Herbicide-Resistance Management, Labeling, Education, Training, and Stewardship.

US Environmental Protection Agency (EPA). 2018a. US EPA Pesticide Product Label, Engenia. EPA Reg. No. 7969-345. Accessed 09/2020. https://www3.epa.gov/pesticides/chem_search/ppls/007969-00345-20181102.pdf

US Environmental Protection Agency (EPA). 2018b. US EPA Pesticide Product Label, FeXapan. EPA Reg. No. 352-913. Accessed 09/2020. https://www3.epa.gov/pesticides/chem_search/ppls/000352-00913-20181105.pdf

US Environmental Protection Agency (EPA). 2018c. US EPA Pesticide Product Label, Xtendimax with Vaporgrip Technology. EPA Reg. No. 524-617. Accessed 09/2020. https://www3.epa.gov/pesticides/chem_search/ppls/000524-00617-20181105.pdf

US Environmental Protection Agency (EPA). 2018d. Over-The-Top Dicamba Products For Genetically Modified Cotton and Soybeans: Benefits and Impacts. Accessed 09/2020. https://www.regulations.gov/document?D=EPA-HQ-OPP-2016-0187-0966

US Environmental Protection Agency (EPA). 2018e. Registration Decision for the Continuation of Uses of Dicamba on Dicamba Tolerant Cotton and Soybean. Accessed 10/2020. https://www.regulations.gov/document?D=EPA-HQ-OPP-2016-0187-0968

Van Wychen L. 2019. 2019 Survey of the Most Common and Troublesome Weeds in Broadleaf Crops, Fruits & Vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Available: http://wssa.net/wp-content/uploads/2019-Weed-Survey_Broadleaf-crops.xlsx

Yourman, L. and B. Chism. 2016. Review of Benefits as Described by the Registrant of Dicamba Herbicide for Postemergence Applications to Soybean and Cotton *and* Addendum Review of the Resistance Management Plan as Described by the Registrant of

Dicamba Herbicide for Use on Genetically Modified Soybean and Cotton. U.S. Environmental Protection Agency.