An Analysis of the Benefits and Risks of 2,4-D Use in Cotton in the United States

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- Cotton is a significant industry in the United States, with revenues exceeding $120 billion and product values over $35 billion.
- With Enlist™ technology, 2,4-D is set to become an effective tool for fighting herbicide-resistant weeds in cotton crops.
- Glyphosate-resistant weeds have, in some cases, forced farmers to return to manual weeding practices, at great expense.

Introduction

Cotton is an important agronomic crop in the southern US, with a tremendous contribution to the economic wellbeing of this region. Cotton is planted on about 12 million acres in the US, with annual revenues exceeding $120 billion. The profitability of US cotton production has been heavily impacted by the evolution and spread of herbicide-resistant weeds. Glyphosate-resistant Palmer amaranth is of particular concern, threatening cotton production in the region. Herbicide-resistant weeds have forced growers to abandon conservation tillage practices and revert back to routine tillage as a tool for managing resistant weeds. In certain areas of the US Midsouth, cotton growers even hire hoe crews to physically remove resistant weeds. There is a critical need for additional weed management tools for tackling herbicide resistance and sustaining profitable cotton production. In response to widespread resistance, the agribusiness industry has developed new tools to manage resistant weeds and the Enlist™ cotton technology developed by Dow AgroSciences™ is a notable one among them.

This technology allows for the use of Enlist-Duo™ herbicide on cotton, which is a mixture of 2,4-D choline salt and glyphosate. No other formulations of 2,4-D will be permitted in Enlist™ cotton. The Enlist™ cotton will also be tolerant to glyphosate and glufosinate to improve management diversity. The potential use of 2,4-D on cotton brings a new weed management tool, which has not been an option previously. 2,4-D can be an effective and economical option for managing tough-to-control and glyphosate-resistant broadleaf weeds in cotton, and it also provides operational flexibility with weed management. The availability of 2,4-D will help cotton growers sustain their weed management programs and improve profitability, particularly in areas where herbicide resistance is widespread. However, there are valid concerns surrounding the use of 2,4-D, notably on the likelihood for unintended drift to nearby sensitive crops, and the possibility for the evolution of 2,4-D resistant weeds. The low volatile choline salt formulation of 2,4-D is expected to reduce drift potential; drift issues can be further minimized with the adoption of proper application technology stewardship practices. The use of 2,4-D in cotton must be integrated with diversified weed management options, including chemical and non-chemical tools to minimize the risk of weeds evolving resistance to 2,4-D. Education and extension programs must be implemented targeting growers, crop consultants, and agrichemical distributors. There should be an emphasis on diversification of weed management options within 2,4-D resistant cotton to steward this technology and provide sustainable weed management.

Cotton Production in the US

Cotton is an important cash crop in the US, valued at more than $35 billion in products and services, and generates about $120 billion in annual business revenue (NCC 2015). Cotton is the number one value-added crop in the US, supporting the rural economies of the major cotton-producing states in the nation. Two different species of cotton are cultivated in the US: pima cotton or extra-long staple cotton (*Gossypium barbadense*) and upland cotton (*G. hirsutum*). Among these two species, the upland cotton is the most widely cultivated species comprising about 98% of the total US cotton acreage (USDA-NASS 2015a).

Genetically-engineered (GE) cultivars with resistance to herbicides, insects, or both, dominate the cotton seed market. In 2014, about 96% of all cotton acreage was planted to a GE cultivar (USDA-ERS 2014a). Herbicide resistance is an important GE trait in cotton, with the acreage planted to herbicide-resistant cotton increasing from only 10% in 1997 to 91% in 2014 (USDA-ERS 2014b).

Table 12.1 Herbicide Resistant Cotton Cultivars in the United States

Herbicide	Event	Developer
Glyphosate	MON88913	Monsanto
	MON1445	Monsanto
	MON1698	Monsanto
	GHB614	Bayer CropScience
Glufosinate	T304-40XGHB119	Bayer CropScience
Phosphinothricin	LLCotton25	Aventis
Bromoxynil	BXN31807	Calgene
	BXN31808	Calgene
Sulfonylurea herbicides	19-51a	DuPont
Dicamba + Glufosinate	MON88701-3	Monsanto
2,4-D + Glufosinate (TBD)	DAS-81910-7	Dow AgroSciences

Additionally, an event with 2,4-D and glufosinate resistance (DAS-81910-7 by Dow AgroSciences) has received preliminary determination of non-regulated status, pending final assessment and decision (APHIS 2015a). This technology (known as the Enlist™ cotton technology) allows for the use of 2,4-D for in-crop weed management in cotton.

Cotton production typically requires warm temperatures and a long growing season of about 180 frost-free days (Smith and Cothren 1999). Thus, the majority of cotton production in the US is limited to the southern regions. Figure 12.2 shows the important cotton producing counties across the southern US cotton belt (USDA-NASS 2015b). USDA-ERS groups US cotton producing areas into six zones: Fruitful Rim (West, South Texas and Florida), Southern Seaboard (Southeast), Eastern Uplands (parts of Mid-south, Southeast and Southwest), Prairie Gateway (Southwest), Mississippi Portal (Delta), and Heartland (Missouri Bootheel). In 2014, cotton was planted in 11 million acres across the southern US, with Texas ranking the top in upland cotton production (6.2 million planted acres), followed by Georgia (1.38 million acres), and North Carolina (0.46 million acres) (USDA-NASS 2015c).

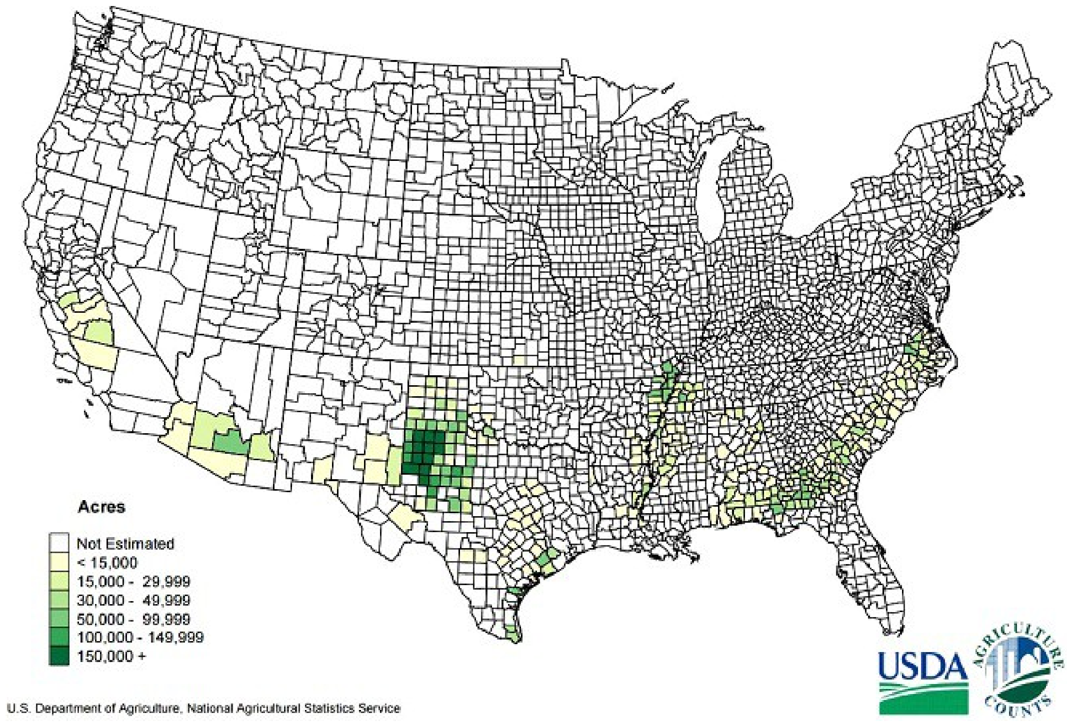

Figure 12.2. Important upland cotton producing regions in the Southern US (USDA-NASS 2015b).

Limited crop rotation is practiced in US cotton production. According to Osteen et al. (2012), cotton has been grown as a monoculture crop in 60-70% of its acreage (Figure 12.3). Monoculture cotton is especially predominant in the Mississippi Delta region (Hake et al. 1991), due in part to higher net returns compared to alternative crops. Further, the need to supply lint to grower-owned ginning mills, as well as participation in cotton commodity support programs, are perceived as factors, which incentivize planting cotton in monoculture (Pettigrew et al. 2006). Alternative crops used in rotation with cotton in the US cotton belt include corn, soybean, sorghum, wheat, peanuts, and fallow.

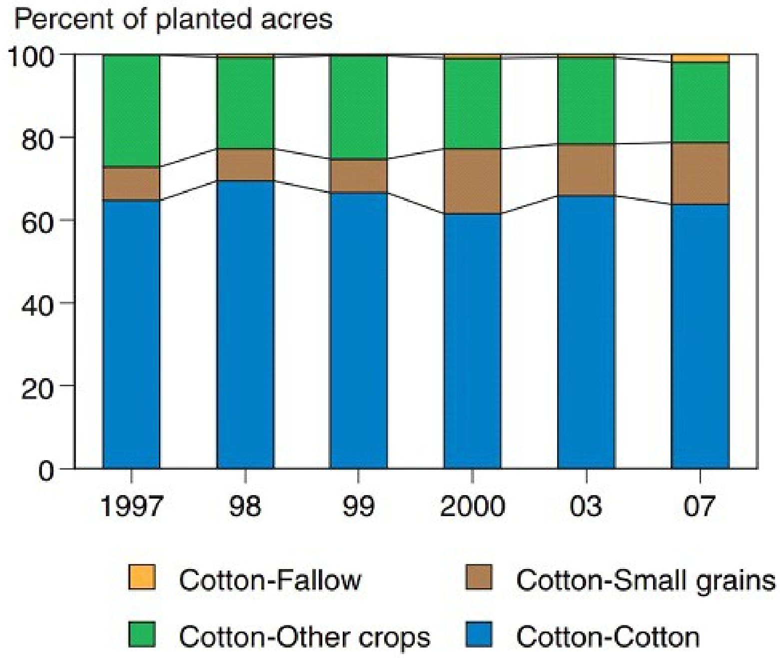

Figure 12.3. Crop rotation trend in US cotton production (Osteen et al. 2012).

Weed Management Issues in Cotton

Historically, weeds have been a major challenge to cotton production and profitability (Chandler and Cooke 1992; Keeley and Thullen 1975). Even low weed densities can cause measurable yield reductions in cotton. For instance, cotton lint yield loss was reported to occur at a meagre density of a single uncontrolled weed escape in a 30-ft row of cotton. Severe yield loss, even complete crop failure can be expected under high weed infestations and in situations where weed control interventions were ineffective. Apart from direct competition for resources, certain weeds can also impact cotton growth and yield due to allelopathic effects (Munger et al. 1984).

In addition to a reduction in quantity of lint and seed, the presence of weeds may also cause other losses (Coble and Byrd 1992). Loss of lint quality is an important concern. The contamination of lint with trash material from weeds and lint staining by chlorophyll and other colored pigment from weeds can result in low lint quality (Garner and Bowen 1961; Smith and Cothren 1999). Furthermore, high-density weed infestations can cause disruptions with harvest equipment, resulting in reduced harvest efficiency, lost time, and increased repairs. Mechanical harvest of cotton was unfeasible when Palmer amaranth (*Amaranthus palmeri*) densities exceeded 6 plants/9.1 m row, due to potential damage to the harvest equipment (Morgan et al. 2001). Because of these issues, most cotton growers have very low tolerance to the presence of weeds in their fields and multiple herbicide applications are typically required to achieve satisfactory weed management. Herbicides are the most widely used pesticides in US cotton production (Figure 12.4), with about 28.8 million pounds of all active ingredients used in 2010, followed by insecticides (7.2 million pounds), and fungicides (0.1 million pounds) (Osteen and Fernandez-Cornejo 2013). Currently, about 95% of total cotton acreage is treated with herbicides.

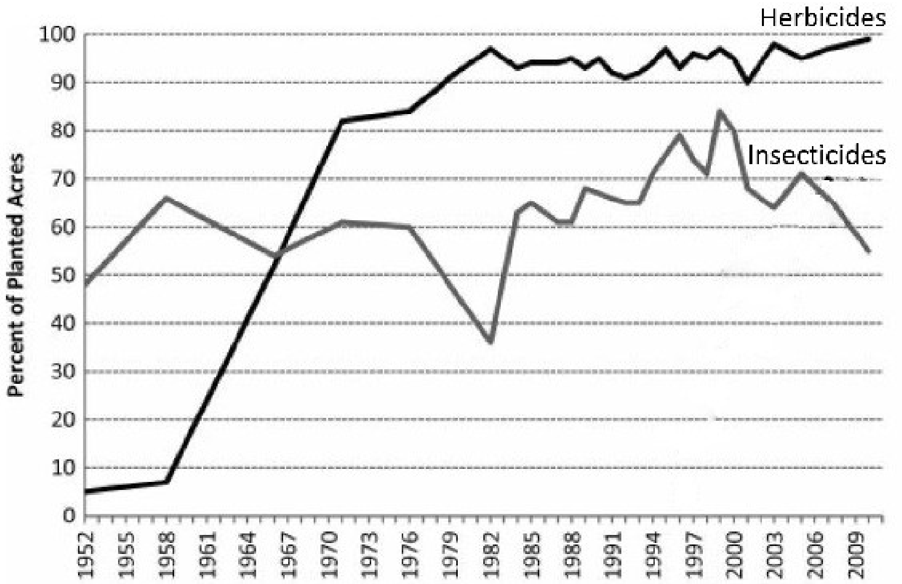

Figure 12.4. Percent of planted cotton acres in 2010 treated with herbicides and insecticides (compiled based on USDA-ERS and USDA-NASS data, by Osteen and Fernandez-Cornejo 2013).

Recently, the evolution and spread of herbicide resistances are causing ineffective weed control and severe economic damages to cotton production. Palmer amaranth is a highly competitive weed species in cotton, and is a problematic herbicide-resistant weed (especially glyphosate resistance) across the cotton belt. Weed surveys conducted across the southern US states revealed that Palmer amaranth was one of the most commonly found weeds in this region (Webster 2009). In Oklahoma, Palmer amaranth interference was shown to reduce cotton lint yield by 5.9 to 11.5% for each increase of one Palmer amaranth plant/33 ft row (Rowland et al. 1999). Research conducted by Morgan et al. (2001) in College Station, TX revealed that Palmer amaranth infestations at a density of 1 to 10 plants/30 ft row can cause a linear reduction in cotton yield from 13 to 54%. Multiple herbicide resistance is also prevalent in Palmer amaranth, with resistance to glyphosate and acetolactate synthase (ALS)- inhibitors reported to occur frequently in Georgia (Sosnoskie et al. 2011) and Arkansas (Bagavathiannan and Norsworthy 2015). Other important resistant weed issues in US cotton production include giant ragweed (*Ambrosia trifida*), horseweed (*Conyza canadensis*), johnsongrass (*Sorghum halepense*), Italian ryegrass (*Lolium perenne* ssp. multiflorum), kochia (*Kochia scoparia*), and goosegrass (*Eleusine indica*) (Heap 2015). A summary of all herbicide-resistant weed cases documented in US cotton production is provided in Table 12.1.

Table 12.1. List of herbicide-resistant weed cases confirmed in southern cotton production.

S.No	Common name	Scientific name	Herbicide MOA	US State(s) reported
1	Goosegrass	*Eleusine indica*	Microtubule inhibitors (K1/3)	AL, AR, GA, MS, NC, SC, TN
			EPSP synthase inhibitors (G/9)	MS
2	Common cocklebur	*Xanthium strumarium*	Nucleic acid inhibitors (Z/17)	AL, AR, LA, MS, NC, SC, TN
3	Horseweed	*Conyza canadensis*	EPSP synthase inhibitors (G/9)	AL, AR, KS, MS, MO, NC, TN
			ALS inhibitors (B/2)	KS
4	Common ragweed	*Ambrosia artemisiifolia*	EPSP synthase inhibitors (G/9)	AL
5	Palmer amaranth	*Amaranthus palmeri*	EPSP synthase inhibitors (G/9)	GA, KS, LA, MO, NC, SC, TN, TX
			Microtubule inhibitors (K1/3)	SC, TN
			ALS inhibitors (B/2)	SC, TN
			ALS inhibitors (B/2) and EPSP synthase inhibitors (G/9)	AZ, AR, GA, SC, TN
6	Tall waterhemp	*Amaranthus tuberculatus*	EPSP synthase inhibitors (G/9)	AR, TN, TX
			ALS inhibitors (B/2)	MO
			ALS inhibitors (B/2) and EPSP synthase inhibitors (G/9)	MO
7	Junglerice	*Echinochloa colona*	EPSP synthase inhibitors (G/9)	CA
8	Kochia	*Kochia scoparia*	EPSP synthase inhibitors (G/9)	KS
9	Johnsongrass	*Sorghum halepense*	ACCase inhibitors (A/1)	LA, MS, TN
			Microtubule inhibitors (K1/3)	MS
10	Italian ryegrass	*Lolium perenne*	EPSP synthase inhibitors (G/9)	LA, MS, NC
11	Spiny amaranth	*Amaranthus spinosus*	EPSP synthase inhibitors (G/9)	MS
12	Common ragweed	*Ambrosia artemisiifolia*	EPSP synthase inhibitors (G/9)	NC
13	Giant ragweed	*Ambrosia trifida*	EPSP synthase inhibitors (G/9)	TN

Source: Heap (2015)

Economic losses (direct and indirect) due to herbicide-resistant weeds are immense in US cotton production. Growers are losing invaluable herbicide tools to weed resistance. Modeling studies suggest that a herbicide lost to resistance is less likely to be effective again on that species due to persistence of the resistance trait in the weed population (Bagavathiannan et al. 2014). Alternative efforts to manage resistant weeds can be very expensive and environmentally less benign. Resistant weeds have increased weed control expenses in cotton (Haire 2010); some growers have even resorted to hand weeding to control resistant Palmer amaranth in cotton, with an average estimated hand-weeding cost of about $59/ha (Riar et al. 2013). In Georgia, cotton growers spend more than $110 million annually to manage Palmer amaranth (Culpepper et al. 2013).

Surveys indicate that herbicide-resistant weed issues have significantly increased herbicide use, hand-weeding, and mechanical tillage (Sosnoskie and Culpepper 2014). Producers are forced to use more and more environmentally less-benign herbicides in their weed management programs, which has a direct impact on the environmental footprint of weed management practices. Over the past several decades, conservation tillage practices have been transforming agriculture with soil, water, and nutrient conservation along with reduced fuel costs and labor savings (Parsch et al. 2001). A report by the conservation technology information center shows that conservation tillage systems have reduced sediment losses over the past two decades by about 60 to 85% across different regions (CTIC 2011). However, the difficulties with managing resistant weeds in conservation tillage systems has forced growers to revert to tillage, jeopardizing the soil conservation gains made over the past several years (Price et al. 2011; Shaw et al. 2012). Surveys conducted during 2005-2006 on tillage trends following the adoption of glyphosate-resistant crops revealed a decline in tillage intensity of 45% in continuous cotton production compared to previous periods (Givens et al. 2009). Surveys conducted on tillage trends during 2007-2012 show a decline in no-till acreage in the Southeast, Midwest, and Midsouth (Monsanto 2013). Overall, herbicide-resistant weeds have increased tillage intensity, herbicide use, human health risks, and the environmental impact of weed management practices in cotton production.

Given the widespread resistance issues, there is a critical need to develop additional options for managing existing resistant weeds and preventing further evolution of resistance. In this regard, 2,4-D presents an opportunity for herbicide resistance management in cotton.

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Opportunities and Benefits of 2,4-D Use in Cotton

Conventional cotton is highly sensitive to 2,4-D (Dunlap 1948), especially at seedling growth stages (McIlrath and Ergle 1953). Because of the hormone-like characteristics, even trace amounts of 2,4-D drift can cause crop injury, delayed maturity, and yield loss. Marple et al. (2008) showed that cotton fibre yields were reduced under simulated 2,4-D drift, with yield reduction increasing with increasing drift rates from 1/1200 to 1/400 of the recommended rate.

2,4-D, however, has been used as an important tank-mix partner for burndown applications prior to planting cotton (Everitt and Keeling 2007). In such situations, a 30-day waiting period between 2,4-D application and cotton planting is typically warranted by the label. In fact, the historical increase in 2,4-D use in cotton from about 1% of the total acreage in 1999 to about 7% in 2010, was due to increased use in burndown applications (USDA-NASS 2014). More recent estimates suggest that 2,4-D is used on 10 to 15% of cotton acreage, amounting to about 700,000 lb ae of the compound each year (USEPA 2012; USDA-NASS 2014). A grower survey conducted in Georgia by Sosnoskie and Culpepper (2014) revealed the increasing use of 2,4-D for burndown applications in cotton, with usage doubling between 2006 and 2010 compared to the period from 2000 to 2005.

Although there is no in-crop use of 2,4-D in cotton, the Enlist™ technology allows for the effective use of 2,4-D for weed management in cotton. The Enlist™ weed management system includes the use of Enlist-Duo™ herbicide, which is a combination of 2,4-D and glyphosate. Notably, the 2,4-D used in the Enlist-Duo™ herbicide is a novel choline salt formulation (Colex-D™ technology), which has low drift potential (DAS 2015). The 2,4-D choline formulation is a quaternary ammonium salt, which is chemically more stable and less volatile. The choline formulation also comes with an improved particle size distribution, which minimizes the potential for particle drift (DAS 2015). The proposed 2,4-D application rate on Enlist™ cotton is 1 lb ae/acre for preemergence (PRE) application or 0.5 to 1 lb ae/acre for postemergence application, with a maximum use rate of 3 lb ae/acre in a growing season (APHIS 2015b).

Field evaluations conducted in the South have revealed the excellent crop safety and weed control benefits provided by the Enlist™ weed management system in cotton (Dixon et al. 2014; Manuchehri et al. 2014). Experiments conducted in Mississippi and Arkansas cotton demonstrated that sequential applications of Enlist-Duo™ at 2.2 kg ae/ha in a program with PRE residual herbicides will be effective in managing glyphosate-resistant Palmer amaranth (Dixon et al. 2014; Edwards et al. 2013; Norsworthy et al. 2013). In Texas High Plains, the Enlist™ cotton technology has a great potential for managing some of the difficult-to- control weeds such as Palmer amaranth, Russian thistle (*Salsoga tragus* L.), and kochia, especially when used as part of a weed management system that incorporates soil residual herbicides (Manuchehri et al. 2014; Reed et al. 2013).

The possibility of using 2,4-D within the Enlist™ cotton weed management system brings an additional tool to the weed management toolbox available for a cotton grower. Thus, 2,4-D will allow for further diversification of weed management in cotton and help improve weed control and profitability. There is a critical need for such alternative tools to effectively tackle existing weed resistance to glyphosate and other herbicides and also minimize the risk of future resistance evolution to alternative herbicide technologies. The Enlist™ cotton cultivars are also resistant to glyphosate and glufosinate and thus improve the diversity of options on susceptible weeds.

As indicated previously, 2,4-D will be an excellent tool for managing glyphosate-resistant weeds, particularly Palmer amaranth which is devastating US cotton production (Norsworthy et al. 2013). 2,4-D is effective in controlling 9 of the 13 herbicide-resistant weeds (listed in Table 12.1) infesting US cotton production. Further, the proposed Enlist-Duo™ label for cotton is expected to allow burndown 2,4-D applications without the typical 30-day waiting period required for other formulations of 2,4-D (APHIS 2015b), which would provide more flexibility to growers on pre-plant weed control and cotton planting. The Enlist™ cotton technology also allows for a wider application window for 2,4-D in cotton, which is highly valued by growers. 2,4-D possesses preferable environmental characteristics compared to many alternative herbicides used in cotton production. 2,4-D is regarded as a low risk herbicide in terms of potential human and animal health effects as well as toxicity to the broader environment (USEPA 2001, 2005; USDA-FS 2006). With the adoption of Enlist™ cotton, the use of more harmful and expensive herbicides may be reduced in US cotton production. It is also anticipated that the availability of effective alternative chemistries such as 2,4-D for weed control in cotton will promote the adoption of no-till and conservation tillage practices.

2,4-D is also an important herbicide used in boll weevil eradication programs. As part of this program, volunteer cotton stands are required to be eliminated during early season as well as post-harvest to prevent the survival of the insect population. Cotton stalks are typically shred following harvest, but regrowth occurs. Chemical stalk destruction is practiced on 55% of the cotton acres in south and east Texas (McCorkle, 2013), and 2,4-D is the most effective and economical herbicide option for cotton stalk destruction (Greenberg et al. 2007; Morgan et al. 2013). The study conducted by Greenberg et al. (2007) demonstrated that 2,4-D dimethyl-ammonium was the best treatment for preventing post-harvest cotton regrowth and fruiting, providing up to 90% stalk destruction when sprayed once immediately after cotton harvest or 100% destruction when sprayed twice at 0 and 14 days after harvest. Seedling emergence may also occur post-harvest or overwinter with a spring emergence from seed cotton dispersed on the soil, resulting in the establishment of volunteer cotton plants. 2,4-D is a recommended herbicide for volunteer cotton control in corn, sorghum, soybean, and wheat (Morgan et al. 2011a), and also in non-auxinic cotton (Morgan et al. 2011b). Moreover, 2,4-D will be beneficial for stalk destruction and volunteer cotton management within the dicamba-tolerant (Bollgard II®XtendFlex™) cotton technology.

Risks and Mitigation Strategies with 2,4-D Use in Cotton

While the availability of 2,4-D for weed control in cotton could provide numerous operational benefits, the use of this herbicide in agricultural landscapes poses significant risks. There are some unintended risks posed to the broader environment by the widespread use of 2,4-D, which were extensively reviewed (USEPA 2001, USEPA 2005, and APHIS 2015b) and strategies for risk mitigation and management were outlined. The present analysis focuses on risks to the crop production systems on the likely use of 2,4-D in cotton.

The first and foremost concern is the potential for off-target movement of 2,4-D through drift, particularly vapor drift (Grover et al. 1972; White et al. 1976). Vapor drift occurs during temperature inversions, and is more problematic than particle drift due to greater potential for long-distance movement of vapor particles, resulting in severe crop injuries even at farther distances. Vegetables, particularly solanaceous and cucurbitaceous crops, are extremely sensitive to 2,4-D even when exposed to low concentrations (Gilreath et al. 2001; Hemphill and Montgomery 1981; Mohseni-Moghadam and Doohan 2015). Compost material from yard wastes and lawn-clippings pre-exposed to 2,4-D has the potential to injure tomato plants (Bugbee and Saraceno 1994). Likewise, grape vines (*Vitis vinifera* L.), particularly the newly planted ones, are highly sensitive to 2,4-D drift (Al-Khatib et al. 1993; Bhatti et al. 1996). 2,4-D drift may also injure several other crops and orchard trees (Calavan et al. 1956; Doll 2009). As a result, there is a concern among the producers of sensitive crops regarding the increased use of 2,4-D associated with the adoption of Enlist™ weed management systems.

The drift risks associated with 2,4-D use on cotton can be mitigated by a great extent through proper adoption of stewardship practices. The drift potential will be much less with the choline salt formulation present in the Enlist-Duo™ herbicide (DAS 2015). Continued maintenance of local application restrictions will help minimize drift risks to nearby sensitive crops. These restrictions are case-specific and based on local production conditions. For instance, in Fort Bend County, TX, aerial applications and ground applications of high volatile formulations of 2,4-D are prohibited within two miles of any susceptible crop (TDA 2015). Such restrictions are expected to be adequate considering the relatively low-drift potential of the choline salt formulation. It is vital to recognize that drift risks can only be minimized, but not completely eliminated. In this respect, properly following label instructions and stewardship recommendations is critical to minimize drift risks. In particular, proper consideration for nozzle selection, boom height, wind speed, and other environmental conditions is imperative. Dow AgroSciences™ has developed best management practices, collectively known as the Enlist™ Ahead stewardship program, for responsible use of this technology (Peterson 2013; Siebert et al. 2014). Community efforts, such as the Driftwatch programs, would be particularly useful to inform nearby sensitive crops to minimize possible drift issues. There is also a need for establishing mechanisms for providing financial compensations in cases of misapplication or violation of stewardship protocols.

Second, a heavy reliance on 2,4-D and glyphosate alone as an alternative weed management option in cotton is likely to lead to 2,4-D resistance in weed communities. Globally, weed resistance to 2,4-D is relatively rare compared to most other herbicide mechanisms of action (MOA) (Heap 2015; Wright et al. 2010). The rarity of 2,4-D resistance is primarily attributed to the activity of 2,4-D in multiple sites in the plant and complexity in auxin signal response (Mithila et al. 2011; Walsh et al. 2006). However 2,4-D resistance is not uncommon among weed communities.

Repeated use of 2,4-D has been found to select for 2,4-D resistant weed populations (e.g., Burke et al. 2009). By 2015, at least 17 weed species have evolved resistance to 2,4-D worldwide (Table 12.2). High frequency of 2,4-D use, combined with less management diversity, is expected to lead to more cases of 2,4-D resistance. The Enlist-Duo™ herbicide consists of two herbicide MOAs (EPSPS-inhibitor, synthetic auxin). However, there is only a single effective MOA on glyphosate-resistant weeds; thus, sole reliance on Enlist-Duo™ will greatly increase the selection pressure for 2,4-D and favor multiple resistance. Furthermore, use of Enlist-Duo™ alone will favor glyphosate resistance in grasses. Mortensen et al. (2012) raised concerns that new stacked herbicide resistance technologies such as the Enlist™ cotton only provide a temporary solution and will eventually undermine sustainable weed management through increased severity of multiple-resistant weeds.

The risk of resistance evolution to 2,4-D, including the evolution of multiple-resistant weed populations is real, and proper adoption of herbicide resistance stewardship practices is critical. 2,4-D must be used in combination with other herbicide MOAs and non-chemical tactics. One additional option available in the Enlist™ technology is integration of glufosinate to protect against the evolution of resistance to 2,4-D. Growers must place greater emphasis on proactive resistance management, focusing on diversifying weed management tactics (Norsworthy et al. 2012). Such tactics must aim at utilizing all available weed management tools (both chemical and non-chemical options) at one’s disposal including, but not limited to, crop rotation, rotating crop traits, stale seedbed, use of soil residual herbicides, rotating herbicide MOA, mechanical options where possible, and cultural tactics.

Table 12.2. Weed species that have evolved resistance to 2,4-D worldwide.

S.No.	Common name	Scientific name	Year	Location
1	Wild carrot	*Daucus carota*	1952	Ontario (Canada)
			1993	Michigan
			1994	Ohio
2	Dayflower	*Commelina diffusa*	1957	Hawaii
3	Field bindweed	*Convolvulus arvensis*	1964	Kansas
4	Musk thistle	*Carduus nutans*	1981	New Zealand
5	Scentless chamomile	*Matricaria perforata*	1975	France, UK
6	Gooseweed	*Spenoclea zeylanica*	1983	Philippines
			1995	Malaysia
			2000	Thailand
7	Canada thistle	*Cirsium arvense*	1985	Hungary
8	Globe fringerush	*Fimbristylis miliacea*	1989	Malaysia
9	Wild mustard	*Sinapis arvensis*	1990	Manitoba
10	Corn poppy	*Papaver rhoeas*	1993	Spain
11	Yellow bur-head	*Limnocharis flava*	1998	Malaysia
12	Italian thistle	*Carduus pycnocephalus*	1997	New Zealand
13	Wild radish	*Raphanus raphanistrum*	1999	Australia
14	Marshweed	*Limnophila erecta*	2002	Malaysia
15	Indian hedge mustard	*Sisymbrium orientale*	2005	Australia
16	Prickly lettuce	*Lactuca serriola*	2007	Washington
17	Common waterhemp	*Amaranthus tuberculatus*	2009	Nebraska

Source: Heap (2015)

Third, 2,4-D will no longer be useful for stalk destruction in Enlist™ cotton, perhaps reducing the benefits of 2,4-D in non-crop cotton management. Lassiter et al. (2014) found that application of dicamba + 2,4-DP or dicamba+diflufenzopyr is effective in terminating Enlist™ cotton stalks post-harvest. More research is necessary to find suitable options for stalk destruction and volunteer cotton management under different situations.

Conclusion

The use of 2,4-D for weed management in cotton is beneficial to the cotton industry in effectively managing some of the difficult-to-control and herbicide-resistant weeds devastating the industry and also in providing operational flexibility. Users of this tool must understand and employ appropriate stewardship practices to minimize unintended risks and preserve the utility of this technology. More investments in education and extension programs are vital in educating the growers, consultants, and agrichemical distributors with technology stewardship.

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