Importance of 2,4-D and Other Phenoxy Herbicides in Herbicide Resistance Management

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- There are 33 different weed species in the United States that are resistant to one or more herbicide mechanisms of action.
- Of these resistant species, 25 are effectively controlled by 2,4-D.
- After more than 70 years of use, only 7 species of weed have become resistant to 2,4-D, leaving it as an effective tool for managing weeds resistant to other herbicides.

Introduction

2,4-D, and its analogs (e.g., MCPA) are widely used in agriculture to selectively control broadleaf weeds in cereal crops and non-cropland. The use of 2,4-D in cereal crops revolutionized agricultural production throughout the world.

2,4-D and its analogs are inexpensive and do not have prolonged soil residual activity (WSSA Handbook 2014). These herbicides have been a preferred choice for broadleaf weed control in cereal crops and have been extensively used worldwide for more than 70 years, primarily because of their selectivity, efficacy, wide spectrum of weed control, and low application costs. The use of 2,4-D has increased in the United States, Canada, and other countries since their commercialization of row crops, as well as in non-crops systems (Rias, Inc. 2006).

Herbicide Resistant Weeds

The evolution of herbicide resistant weed biotypes is a serious problem facing US agriculture. Currently there are 33 broadleaf species in the US with herbicide resistant populations to 11 different mechanisms of action (MOA) (Table 13.1) (Heap 2014). Amongst the herbicide resistant broadleaf species, the majority of these cases are resistant to photosystem II inhibitors (PSII), acetolactate synthase inhibitors (ALS), and glyphosate (EPSPS) (Table 13.2) (Heap 2014)

More alarming is the evolution of weed populations that are resistant to multiple herbicide mechanisms of action. In the US, there are over 41 different populations of broadleaf weeds with resistance to two or more MOAs (Heap 2014). These species include waterhemp, kochia, and Palmer amaranth, which are some of the most pernicious weeds in crops and pastures.

Table 13.1. The distribution of herbicide resistant weed biotypes in the United States. An "X" in a box under each state indicates there is at least one herbicide resistant population of that species in that state. The "X" under the "2,4-D" indicates that that weed species is controlled by 2,4-D based on the label or state recommendation.

#	2,4-D	Common Name	Species	AL	AZ	AR	CA	C	C	D	F	GA	HI	ID	IL	IN	IA	K	K	LA
1	x	Beggarstick	Bidens alba																	
2	x	Bur-weed marsh-elder	Iva xanthifolia																	
3	x	Chickweed	Stellaria media							x									x	
4	x	Cocklebur	Xanthium strumarium	x		x									x		x	x		x
5	x	Common groundsel	Senecio vulgaris														x			
6	x	Common lambsquarter	Chenopodium album						x	x					x	x				
7	x	Common purslane	Portulaca oleracea																	
8	x	Common ragweed	Ambrosia artemisiifolia			x				x					x	x		x	x	
9	x	Fleabane	Conyza bonariensis				x													
10	x	Flixweed, tansymustard	Descurainia sophia															x		
11	x	Giant ragweed	Ambrosia trifida	x		x									x	x	x	x	x	x
12	x	Horseweed	Conyza canadensis																	
13	x	Livid pigweed	Amaranthus blitum (ssp. oleraceus)																	
14	x	Palmer amaranth	Amaranthus palmeri		x	x				x	x	x			x	x	x	x	x	x
15	x	Prickly sida	Sida spinosa																	
16	x	Redroot pigweed	Amaranthus retroflexus						x	x				x		x	x	x	x	
17	x	Russian thistle	Salsola tragus											x						
18	x	Shepard's purse	Capsella bursa-pastoris																	
19	x	Smooth pigweed	Amaranthus hybridus																	
20	x	Spreading wallflower	Ersimum repandum															x		
21	x	Spreading dayflower	Commelina diffusa										x							
22	x	Tall waterhemp	Amaranthus tuberculatus (=A. rudis)			x				x					x	x	x	x	x	
23	x	Velvetleaf	Abutilon theophrasti																	
24	x	White mustard	Sinapis arvensis																	
25	x	Prickly lettuce	Lactuca serriola												x					
26	x	Wild sunflower	Helianthus annuus															x		
27		American nightshade	Solanum americanum								x									
28		Eastern black nightshade	Solanum ptycanthum																	
29		Kochia	Kochia scoparia					x						x	x			x		
30		Lady's thumb	Polygonum persicaria																	
31		Pennsylvania smartweed	Polygonum pensylvanicum														x			
32		Stinking chamomile	Anthemis cotula												x					
33		Wild carrot	Daucus carota																	
			Total	3	1	6	2	2	2	7	2	2	1	5	9	7	8	10	7	2

Table 13.1 (continued). The distribution of herbicide resistant weed biotypes in the United States. An "X" in a box under each state indicates there is at least one herbicide resistant population of that species in that state. The "X" under the "2,4-D" indicates that that weed species is controlled by 2,4-D based on the label or state recommendation.

#	2,4-D	Common Name	Species	ME	M	MA	MI	MN	MS	MO	MT	N	NV	NH	N	NM	N	NC	ND	OH
1	x	Beggarstick	Bidens alba																	
2	x	Bur-weed marsh-elder	Iva xanthifolia																x	
3	x	Chickweed	Stellaria media		x															
4	x	Cocklebur	Xanthium strumarium		x				x									x	x	
5	x	Common groundsel	Senecio vulgaris				x										x			
6	x	Common lambsquarter	Chenopodium album	x	x	x	x							x		x	x	x	x	x
7	x	Common purslane	Portulaca oleracea				x													
8	x	Common ragweed	Ambrosia artemisiifolia				x	x	x	x		x		x		x	x	x	x	x
9	x	Fleabane	Conyza bonariensis																	
10	x	Flixweed, tansymustard	Descurainia sophia																	
11	x	Giant ragweed	Ambrosia trifida					x	x	x		x								x
12	x	Horseweed	Conyza canadensis		x		x		x			x						x	x	x
13	x	Livid pigweed	Amaranthus blitum (ssp. oleraceus)												x					
14	x	Palmer amaranth	Amaranthus palmeri		x		x		x	x		x			x	x		x		x
15	x	Prickly sida	Sida spinosa																	
16	x	Redroot pigweed	Amaranthus retroflexus	x	x		x							x					x	x
17	x	Russian thistle	Salsola tragus								x									
18	x	Shepard's purse	Capsella bursa-pastoris																	
19	x	Smooth pigweed	Amaranthus hybridus		x		x								x		x			
20	x	Spreading wallflower	Ersimum repandum																	
21	x	Spreading dayflower	Commelina diffusa																	
22	x	Tall waterhemp	Amaranthus tuberculatus (=A. rudis)				x	x	x	x		x							x	x
23	x	Velvetleaf	Abutilon theophrasti		x		x													
24	x	White mustard	Sinapis arvensis																	
25	x	Prickly lettuce	Lactuca serriola																	
26	x	Wild sunflower	Helianthus annuus																	
27		American nightshade	Solanum americanum																	
28		Eastern black nightshade	Solanum ptycanthum				x												x	
29		Kochia	Kochia scoparia				x				x					x			x	
30		Lady's thumb	Polygonum persicaria																	
31		Pennsylvania smartweed	Polygonum pensylvanicum																	
32		Stinking chamomile	Anthemis cotula																	
33		Wild carrot	Daucus carota					x			x									
			Total	2	8	1	14	4	6	5	2	5	0	4	2	4	2	4	4	9

#	2,4-D	Common Name	Species	O	O	PA	RI	S	S	TN	T	UT	VT	VA	WA	WV	WI	WY	Total
1	x	Beggarstick	Bidens alba																0
2	x	Bur-weed marsh-elder	Iva xanthifolia																1
3	x	Chickweed	Stellaria media			x								x					5
4	x	Cocklebur	Xanthium strumarium	x				x											12
5	x	Common groundsel	Senecio vulgaris		x										x				4
6	x	Common lambsquarter	Chenopodium album			x	x							x	x	x	x		19
7	x	Common purslane	Portulaca oleracea																1
8	x	Common ragweed	Ambrosia artemisiifolia			x			x										18
9	x	Fleabane	Conyza bonariensis																1
10	x	Flixweed, tansymustard	Descurainia sophia																1
11	x	Giant ragweed	Ambrosia trifida														x		13
12	x	Horseweed	Conyza canadensis	x		x			x	x				x		x	x		24
13	x	Livid pigweed	Amaranthus blitum (ssp. oleraceus)																1
14	x	Palmer amaranth	Amaranthus palmeri			x		x		x	x		x	x					26
15	x	Prickly sida	Sida spinosa																1
16	x	Redroot pigweed	Amaranthus retroflexus		x	x								x	x	x			18
17	x	Russian thistle	Salsola tragus		x										x				4
18	x	Shepard's purse	Capsella bursa-pastoris		x								x						2
19	x	Smooth pigweed	Amaranthus hybridus			x								x			x		7
20	x	Spreading wallflower	Ersimum repandum																1
21	x	Spreading dayflower	Commelina diffusa																1
22	x	Tall waterhemp	Amaranthus tuberculatus (=A. rudis)	x						x							x		17
23	x	Velvetleaf	Abutilon theophrasti														x		3
24	x	White mustard	Sinapis arvensis																0
25	x	Prickly lettuce	Lactuca serriola		x										x				3
26	x	Wild sunflower	Helianthus annuus						x										2
27		American nightshade	Solanum americanum																1
28		Eastern black nightshade	Solanum ptycanthum														x		4
29		Kochia	Kochia scoparia	x	x				x		x	x			x		x	x	16
30		Lady's thumb	Polygonum persicaria																1
31		Pennsylvania smartweed	Polygonum pensylvanicum																1
32		Stinking chamomile	Anthemis cotula																1
33		Wild carrot	Daucus carota																2
			Total	4	6	7	1	2	4	3	2	1	2	6	6	3	8	1	

Table 13.2. The distribution of herbicide resistance in each state by mechanism of action (MOA). The presence of an “X” in each box indicates that there is at least one resistant weed population to that MOA in that state.

Mode of Action	AL	AZ	AR	CA	CO	CT	DE	FL	GA	HI	ID	IL	IN	IA	K	K	LA	ME	MD	MA	MI	MN	MS	MO	MT	NE
Photosystem II inhibitors	x		x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
ALS inhibitors	x	x		x	x		x	x	x		x	x	x	x	x	x	x		x		x	x	x	x	x	x
EPSP synthase inhibitors	x	x	x	x	x		x	x	x			x	x	x	x	x	x		x		x	x	x	x	x	x
PSI Electron Diverter				x			x	x															x			
Synthetic auxin					x					x	x										x				x	x
Nucleic Acid inhibitor	x		x														x						x			
PPO inhibitors							x					x	x	x	x									x		
HPPD inhibitors												x		x	x											x
Microtuble inhibitors	x		x																							
PSII Inhibitors (ureas & amides)																										x
Glutamine synthesis inhibitors																										
Total	5	2	4	4	4	1	5	3	3	1	3	5	4	5	5	3	4	1	3	1	4	4	5	5	4	6

Table 13.2 (continued). The distribution of herbicide resistance in each state by mechanism of action (MOA). The presence of an “X” in each box indicates that there is at least one resistant weed population to that MOA in that state.

Mode of Action	NV	NH	N	NM	N	NC	ND	OH	O	O	PA	RI	S	S	TN	T	UT	VT	VA	WA	WV	WI	WY	TOTAL
Photosystem II inhibitors		x	x		x	x	x	x		x	x	x			x	x		x	x	x	x	x	x	39
ALS inhibitors			x	x		x	x	x	x	x	x		x	x	x	x	x		x	x		x	x	37
EPSP synthase inhibitors			x	x		x	x	x	x	x	x		x	x	x	x			x		x	x		35
Synthetic auxin																				x				14
PSI Electron Diverter							x	x																9
Nucleic Acid inhibitor						x									x									6
PPO inhibitors																								4
HPPD inhibitors																								2
Microtuble inhibitors													x		x									2
PSII Inhibitors (ureas & amides)																								1
Glutamine synthesis inhibitors										x														1
Total	0	1	3	2	1	4	4	4	2	4	3	1	3	2	5	3	1	1	3	3	2	3	2	169

Herbicide resistant broadleaf weeds occur in 48 of the 50 states.

A survey of weed scientists throughout the US was conducted to determine the extent of herbicide resistant biotypes in various states and the utility of 2,4-D to help manage these biotypes. The responses showed that herbicide resistant broadleaf weeds occur in 48 of the 50 states. There were 33 species identified, with a total of 210 cases of resistance to 11 different MOAs (Tables 13.1 and 13.2). Of these 33 species, 25 of them are controlled by 2,4-D (Table 13.1). Only 7 cases of resistance to the phenoxy herbicide were reported in the United States. (Table 13.2). These cases occurred in 5 species: kochia, wild carrot, spreading dayflower, tall waterhemp and prickly lettuce.

Management of Herbicide Resistant Weeds

The Weed Science Society of America (WSSA) has given increased emphasis on managing the evolution of herbicide resistant weeds. Multiple papers have been published on how resistance arises and on the best management practices (BMP) to mitigate the proliferation of herbicide resistance (Norsworthy et al. 2012). BMPs include the use of multiple MOAs on the weed population to lower the selection pressure from any one MOA.

The economic cost of herbicide resistant weeds can be very high. Herbicide resistance causes greater short-term cost to manage a weed population, resulting in crop yield loss, reduced commodity prices due to weed-seed contamination, reduced land values, increased cost in mechanical and cultural controls, and increased costs of alternative herbicides (Norsworthy et al., 2012). Glyphosate-resistant (GR) horseweed in the US resulted in a net increase in production cost of \$11.50/acre^{-1} in soybean (Mueller et al. 2005). GR Palmer amaranth in cotton production in Georgia and Arkansas increased weed management cost by \$19.43/acre^{-1} (Vencill et al. 2012). A similar net cost increase in weed management in soybeans was reported in Missouri to control GR common waterhemp (Legleiter et al. 2009).

2,4-D and its analogs play a major role in an integrated approach for herbicide resistance management. They have a very low risk of selecting for resistance (Beckie 2006). These herbicides are highly effective in controlling many of the multiple-resistant populations of horseweed, Palmer amaranth, common and giant ragweed, and waterhemp. Recommendations for managing herbicide resistant broadleaf populations include the judicious application of 2,4-D either as a pre-plant burndown or POST in 2,4-D tolerant crops.

<u>New 2,4-D Tolerant Crops</u>

The introduction of GR varieties of soybeans, cotton and corn in 1996 revolutionized weed management in these crops. Farmers quickly adopted GR crops because of the simplicity of the glyphosate-based system which provided economical, effective weed control. However, the widespread use of this system across millions of acres over multiple years resulted in the evolution of GR populations in horseweed, Palmer amaranth, common and giant ragweed and tall waterhemp (Heap 2014). These GR populations, particularly in Palmer amaranth, led to the collapse of the simple weed management in cotton and soybeans (Culpepper et al. 2012). Farmers had to abandon fields due to their inability to control this highly competitive weed. Farmers spent up to \$52.60/acre^{-1} for additional herbicides, but this was not enough to control GR Palmer amaranth. Farmers are forced to hire labor to manually remove the weeds from the field (Culpepper et al. 2012).

In response to the spreading problem of GR weeds, Dow AgroSciences developed new 2,4-D resistant varieties of soybean, cotton and corn. These new varieties contain a gene which allows the plant to rapidly metabolize 2,4-D to non-phytotoxic metabolites (Johnson et al. 2014). The decision to introduce 2,4-D resistance into crops was due to several reasons. First, 2,4-D and its analogs have shown excellent resilience and few herbicide resistant weeds have occurred after more than 60 years of use. Second, these herbicides provide excellent control of glyphosate-resistant broadleaf weeds such as Palmer amaranth, horseweed common and giant ragweed, and common waterhemp as well as controlling other broadleaf weeds. These new varieties will also be resistant to glyphosate and glufosinate. The first registration by EPA of new soybean varieties with glyphosate and glufosinate resistance was granted in October,2014 (EPA 2014). The use of 2,4-D in combination with other broadleaf herbicides will reduce the evolutionary selection pressure from glyphosate and glufosinate and should extend the utility of all three classes of herbicides.

Consequences of the Loss of 2,4-D on Herbicide Resistant Weed Management

The loss of 2,4-D and its analogs would be devastating to herbicide resistance management. The broad spectrum of broadleaf weeds controlled by 2,4-D makes it an ideal partner with other MOAs. The rise of multiple resistant biotypes of Palmer amaranth and waterhemp is very concerning. There are already populations of both species which have resistance to glyphosate, PSII inhibitors, ALS inhibitors, HPPD inhibitors and PPO inhibitors.

The loss of 2,4-D and its analogs would be devastating to herbicide resistance management. The broad spectrum of broadleaf weeds controlled by 2,4-D makes it an ideal partner with other MOAs.

There are very few herbicides left to control such biotypes. Phenoxy herbicides, including 2,4-D are the only option left for POST activity. While pre-emergent herbicides, such as the acentanildes and dinitroanilines can be effective in controlling these multiple resistant populations, they are often not completely effective and are highly dependent on environmental conditions, such as adequate rainfall, to be active. It is critical that there are still some POST options available. 2,4-D is one of these vital options.

The introduction of 2,4-D tolerant varieties of soybeans and cotton mean these herbicides can be even more widely used. The loss of 2,4-D will take away this effective tool for broadleaf weed management and will force farmers to be even more dependent on other MOAs, which will lead to increased resistance and loss of effective weed management. These losses will cascade into increased cost of weed management and the accompanying loss of yield. It is essential that 2,4-D and the phenoxy herbicides remain available to farmers to maintain a cost effective and sustainable weed management program.

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