Use of 2,4-D and Other Phenoxy Herbicides in Small Grains in the United States

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- 2,4-D is an inexpensive and effective tool for weed control and herbicide resistance management in small grains.
- 13.4 million acres of winter wheat alone were treated with 4.04 million pounds of 2,4-D in 2012, demonstrating the utility of the herbicide.
- Alternative herbicides are either less effective or more expensive, while manual weed control is astronomically more costly and difficult due to planting practices in small grains.
- On a per acre basis, no herbicide controls as many weeds as inexpensively as 2,4-D.

Introduction

Phenoxy herbicides, such as 2,4-D and MCPA, are used widely for broadleaf weed control in small grains. Phenoxy herbicides registered for small grains are 2,4-D and MCPA. Both have unique advantages in crop safety, effectiveness, and cost. The loss of only 2,4-D would cause a shift to greater usage of MCPA, bromoxynil, clopyralid, and fluroxypyr, and other more expensive alternatives. Net societal loss from banning either 2,4-D or all phenoxy herbicides includes a variety of costs; from changes in tillage and cropping practices; extra weed control cost for alternative inputs; reduced crop production where alternatives may not adequately control weeds or are too expensive; and ultimately increased costs to consumers from higher prices at the market. This loss does not, however, include the broader detrimental impact on integrated pest management. In the short term, reducing herbicide options impacts efforts to optimize weed control, specifically against problem weeds. There is also the long-term impact of limiting herbicide options to respond to the development of weeds resistant to herbicides. The phenoxy herbicides have been used for nearly 70 years without development of major weed resistance problems, and they are still highly effective and affordable inputs for controlling many of the prevalent weed species infesting small grains in the United States (US).

> *Net societal loss, for banning either 2,4-D or all phenoxy herbicides, includes costs associated with changes in tillage and cropping practices; extra weed control cost for alternative inputs; reduced crop production, where alternatives may not adequately control weeds or are too expensive; and ultimately increased costs to consumers from higher prices at the market.*

Usage Trends

Pesticide usage data were obtained from the National Agricultural Statistics Service (NASS).

Overall, small grain acreage has declined in the US since the last phenoxy herbicide benefit assessment. Between 1991 and 2012, land used for wheat alone decreased from 70 million acres to 55 million acres. However, small grain acreage continues to be a critical part of the US economy. Small grains (wheat, barley, oat, and rye) occupied nearly 63 million acres of cropland in the US in 2012 (NASS 2015). In 2012, there were 3.7 million acres of barley, 2.7 million acres of oat, and 1.2 million acres of rye grown mainly in the northern areas of the US (Figure 6.1).

Herbicide use in small grains can fluctuate over time and across geography, depending on growing conditions and commodity prices. In general, herbicide use has increased in small grains, particularly winter wheat (Figure 6.2). Historically, herbicide use was much greater in spring wheat and for the most part it still is (Figure 6.3). Use of 2,4-D is also greater in spring wheat-- which is grown mostly in the northern part of the Great Plains-- than in winter wheat, which is grown throughout the US. Winter-type small grains are generally higher yielding and more competitive with broadleaf weeds than spring grains. Barley and oat are mostly spring grains, but are quite competitive. As a consequence, only a minority of the acres of barley and oat are treated with a herbicide, and increases to the cost of herbicides (such as if phenoxies were no longer available) would make application prohibitively expensive, in many cases reducing crop yields and raising food prices.

Figure 6.1. Small grains acreage in NASS surveyed program states from 1990 to 2014 (NASS 2015).

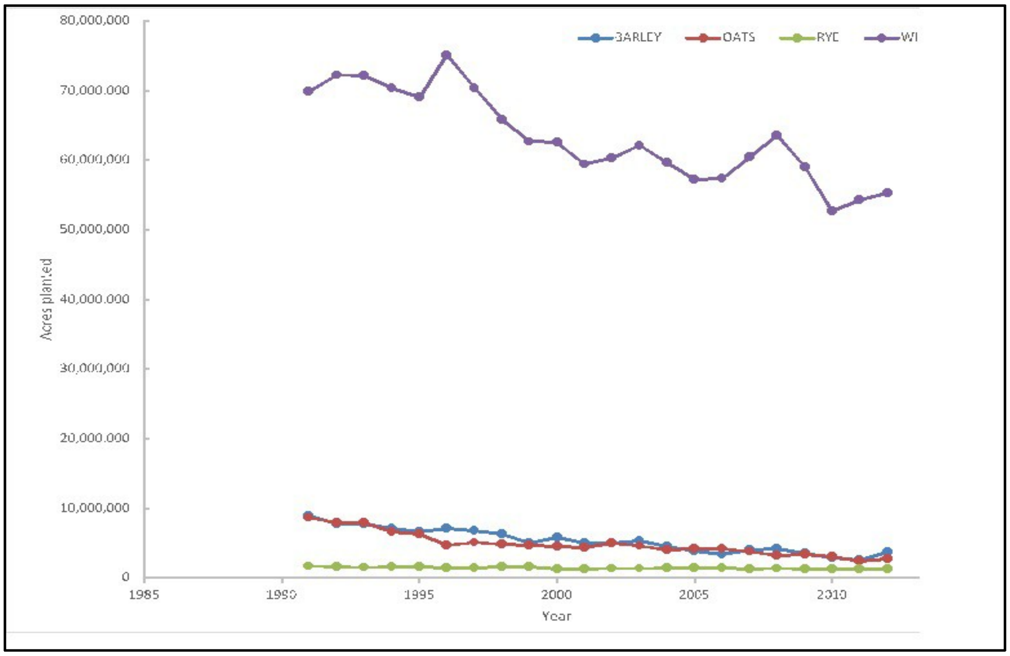


Figure 6.2. Percent of winter wheat acreage in program states treated with 2,4-D (as various salts) and other growth regulating herbicides from 1990 to 2012.

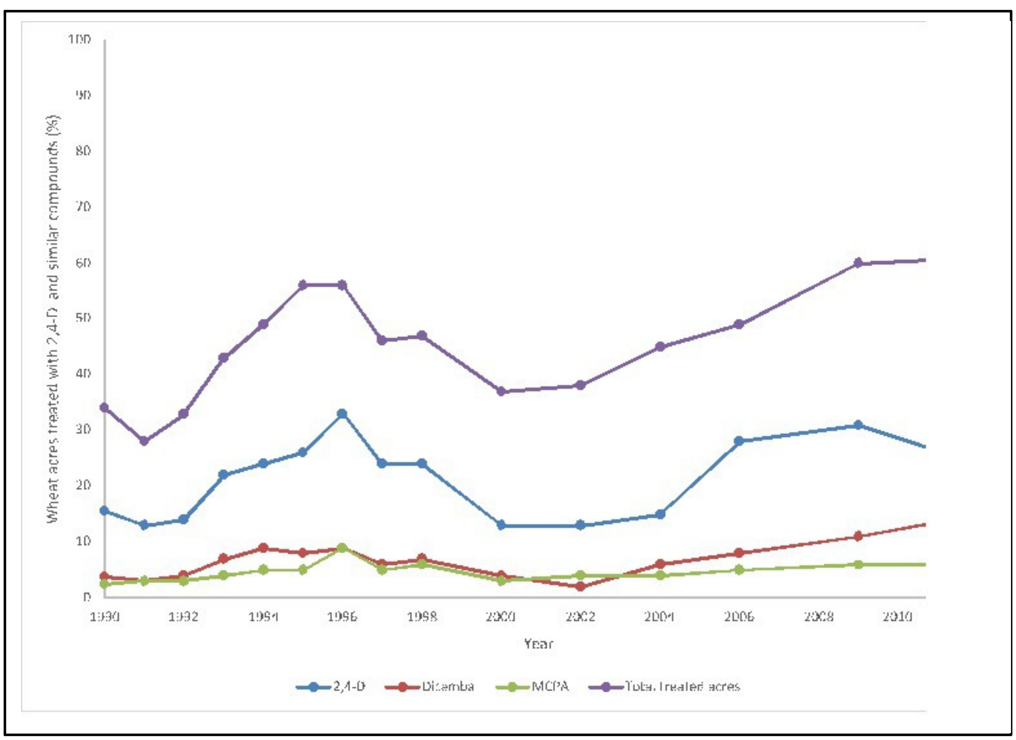


Figure 6.3. Percent of spring wheat acreage in program states treated with growth regulating herbicides from 1990 to 2009.

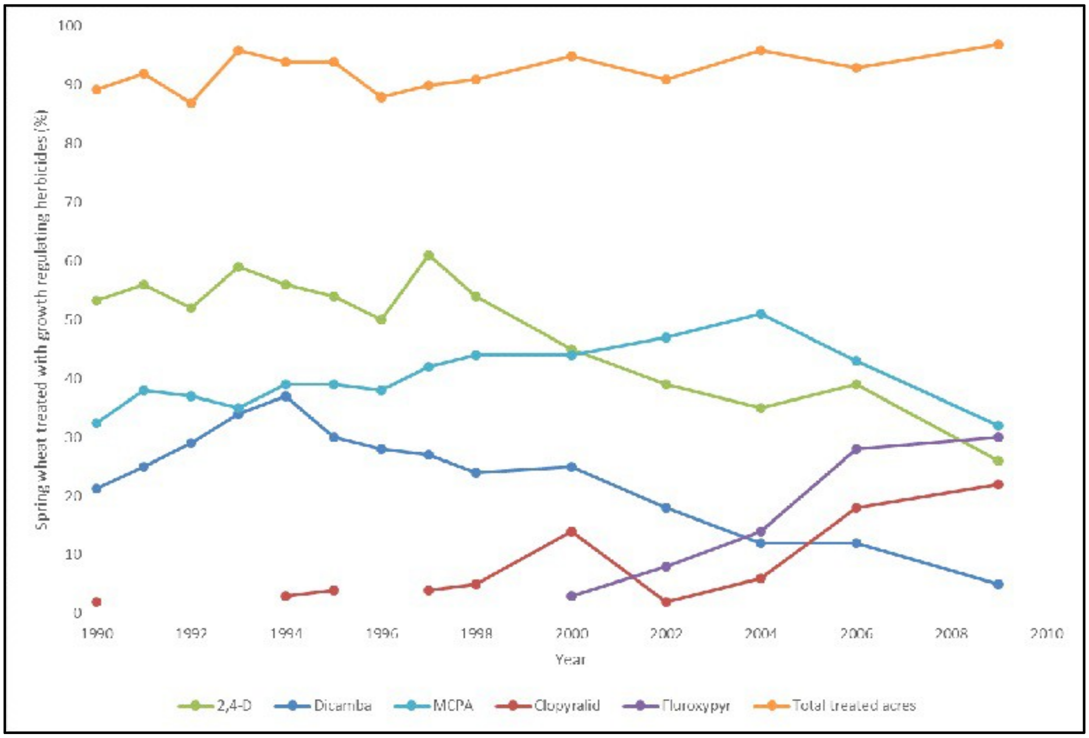
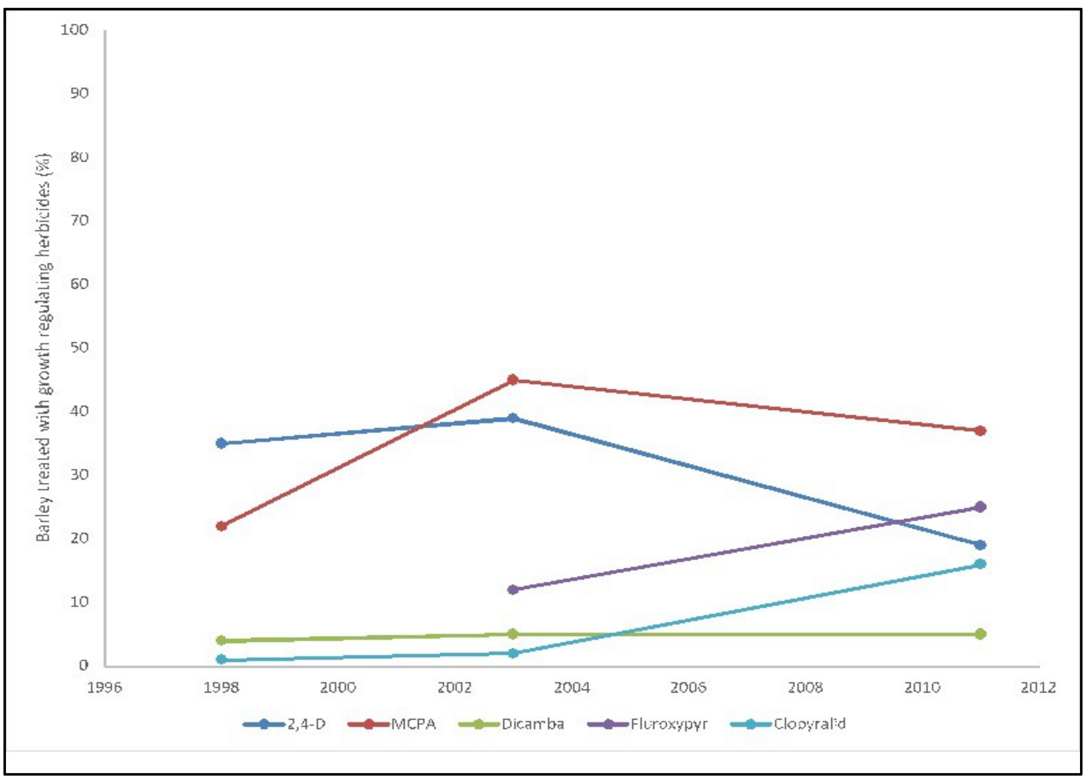


Figure 6.4. Percent of barley acres in program states treated with growth regulating herbicides from 1998 to 2009.



Ninety-seven percent of spring wheat acreage is treated with an herbicide. Herbicide usage in spring wheat ranges from a low of 50% of planted acres in Colorado to a high of 99% in Washington (NASS 2015). The most commonly used herbicides were 2,4-D and MCPA, either alone or in combination with dicamba. Both 2,4-D and MCPA are highly effective in controlling wild mustard species, highly problematic weed in small grains since the early 1900's (Pavlychenko and Harrington 1935). The introduction of 2,4-D in 1945 allowed for a reduction in fallow rotations and intensive tillage, which had been conducted specifically for weed control (Smith and Young 2000).

Loss estimates, losses from cancellation of registration of either 2,4-D or all phenoxy herbicides, costs of alternative herbicides or weed control practices, changes in crop production, and information supporting the major need for retaining phenoxy herbicides were based on survey data produced by Nalewaja (1993). The survey data were obtained by contacting weed scientists or crop production specialists in each state and Puerto Rico. The information was obtained through a mail response to a questionnaire with telephone follow-up. Additionally, assessment teams contacted specialists in an attempt to determine complete coverage of crop acreage. Wild mustard continues to be a problem weed in spring seeded small grains, even with extensive usage of 2,4-D since the late 1940's (Mulligan and Bailey 1975, Nalewaja and Arnold 1970). Wild mustard seed has long viability in the soil, so seed produced in a given year in the crop rotation will cause infestations for many subsequent years (Mulligan and Bailey 1975).

The high cost of labor and difficult access caused by narrow rows make hand weeding prohibitive as a weed control method in small grains. Furthermore, the soil erosion associated with intensive tillage for seedbed preparation or fallow limits these practices for weed control by conservation-minded growers. Spring small grains are grown in areas not adapted to many alternate crops to aid in weed management, which accounts for the extensive herbicide usage in the spring wheat area.

Wheat

The phenoxy herbicides 2,4-D, MCPA, and dicamba are used for weed management in wheat production. Clopyralid and fluroxypyr are also used – fluroxypyr use has increased in recent years. The NASS survey reports about 24% of winter wheat acres were treated with 2,4-D in 2012, equivalent to ~13.4 million acres (Table 6.1). Use of 2,4-D in spring wheat is also extensive, with 26% of the spring wheat acres treated (Table 6.2). For both winter and spring wheat, from1990 to 2012, the total treated area varied considerably, but the percent treated acres remained more consistent. An estimated 4.04 million pounds of 2,4-D per year were used in winter wheat at an average rate of 0.37 lb/A, for an estimated annual cost of $28 million. An additional 1.37 million pounds of 2,4-D were applied in spring wheat. MCPA use was estimated to be approximately 574,000 pounds per year in winter wheat and 1.13 million pounds in spring wheat. Use rate of MCPA was dependent upon the formulation and varied from 0.256lb/A for the isoctyl ester to 0.507 lb/A for the dimethylamine salt. Use of 2,4-D is uniformly extensive across different regions (Figure 6.5), with ~30% of the treated acres receiving an application per year. The use of MCPA varies by region. It is used primarily in the northern Great Plains, the Pacific Northwest, and southern Idaho, and is much more commonly used in spring wheat than in winter wheat.

Table 6.1. Winter wheat broadleaf herbicide use by area treated, number of applications, rate per application, total material applied, including formulations of 2,4-D, in program states1 in 2012.

Herbicides[2]	Area applied	Applications	Rate per application	Total applied	Cost[3]
	%	#	lbs per A	1,000 lbs	$ per A
2,4-EHE (30063)	1	1.4	0.377	2,385	3.02
2,4-D, DMA salt (30019)	1	1.6	0.285	1,655	1.5
2,4-D, ISP salt (30025)	(Z	2.1	0.062	16	0.74
Dicamba, diglycoamine salt (128931)	1	1.2	0.115	27	1.61
Dicamba, dimethylamine salt (29802)	1	1.3	0.149	878	2.05
Dicamba, sodium salt (29806)	3	1.7	0.093	89	9.67
MCPA, 2-ethylhexyl (30564)	5	1	0.296	462	2.81
MCPA, dimethylamine salt (30516)	(	1.1	0.507	55	5.07
MCPA, isoctyl ester (30563)	1	1	0.256	57	5.32
Clopyralid, mono salt (117401)	(	1	0.101	32	8.08
Fluroxypyr 1-MHE (128968)	3	1	0.096	98	7.68
Bromoxynil, heptanoate (128920)	3	1.1	0.122	147	5.49
Bromoxynil octanoate (35302)	6	1.1	0.184	410	8.28
Chlorsulfuron (118601)	1	1	0.007	28	1.57
Metsulfuron-methyl (122010)	1	1.1	0.003	15	0.48
Thifensulfuron-methyl (128845)	1	1.1	0.009	41	1.34
Tribenuron-methyl (128887)	1	1	0.004	20	1.02
Triasulfuron (128969)	4	1	0.017	25	3.99

[1] Program states include Arkansas, California, Colorado, Georgia, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, and Washington, and represent 38,190,000 of the 55,294,000 total national wheat acres.

[2] Numbers in parentheses are EPA chemical codes for the active ingredient.

[3] Cost of the herbicide application at the average rate using approximate average retail price for small quantities.

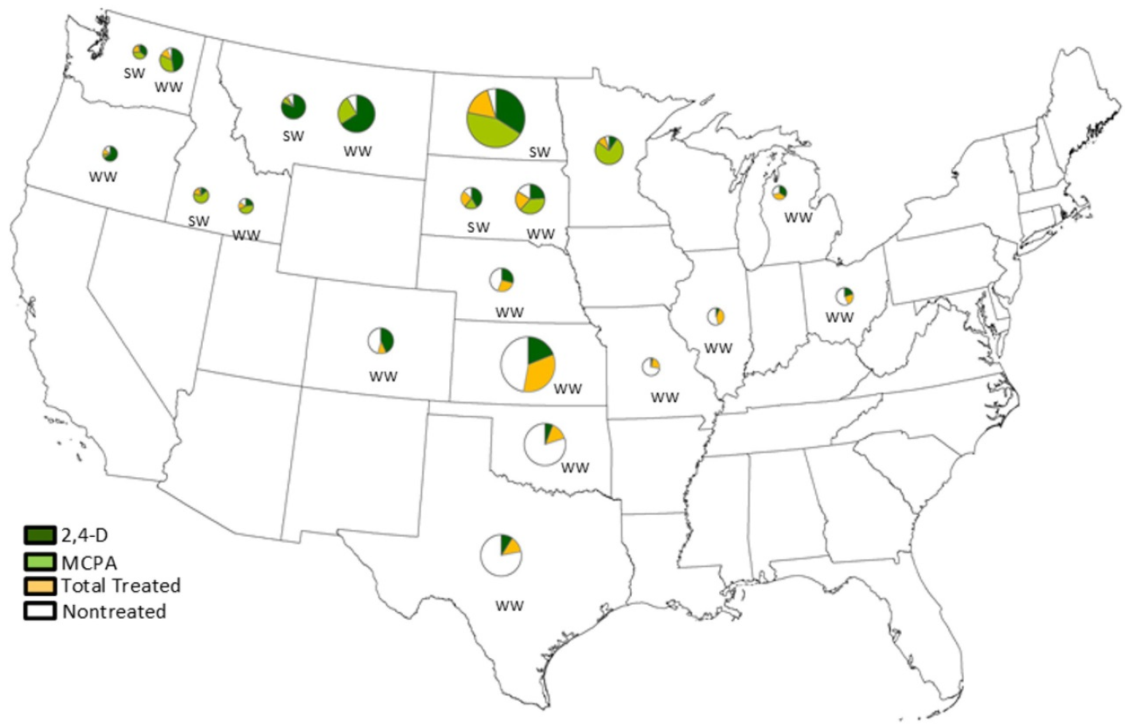
[4] (Z) Less than 0.5% area applied.

Table 6.2. Spring wheat broadleaf herbicide use, including formulations of 2,4-D, in program states1 in 2009.

Herbicides	Area treated	Applications	Rate per application	Total applied	Cost[3]
	%	#	lbs ai per A	1,000 lbs	$ per A
2,4-D, EHE (30063)	17	1.2	0.38	1,026	3.04
2,4-D, diethylamine salt (30016)	(Z)[4]	1	0.589	16	5.43
2,4-D, DMA salt (30019)	5	1	0.382	269	2.01
2,4-D, ISP salt (30025)	3	1	0.059	23	0.71
2,4-D, triiso. Salt (30035)	1	1	0.355	32	4.44
Dicamba, diglycoamine salt (128931)	1	1.4	0.095	15	1.33
Dicamba, dimethylamine salt (29802)	3	1	0.098	41	1.35
Dicamba, sodium salt (29806)	1	1	0.109	10	11.33
MCPA, 2-ethylhexyl (30564)	25	1.1	0.268	912	2.55
MCPA, dimethylamine salt (30516)	1	1	0.346	63	3.46
MCPA, isoctyl ester (30563)	5	1	0.218	156	4.53
Clopyralid (117403)	21	1	0.08	233	6.4
Fluroxypyr 1-MHE (128968)	27	1	0.086	306	6.88
Bromoxynil, heptanoate (128920)	25	1	0.151	504	6.80
Bromoxynil octanoate (35302)	43	1	0.188	1,098	8.46
Metsulfuron-methyl (122010)	5	1.2	0.002	2	0.32
Thifensulfuron-methyl (128845)	25	1	0.009	32	1.34
Tribenuron-methyl (128887)	25	1	0.004	14	1.02

[1] Program states include Colorado, Idaho, Minnesota, Montana, North Dakota, Oregon, South Dakota, and Washington
[2] Numbers in parentheses are EPA chemical codes for the active ingredient
[3] Cost of the herbicide application at the average rate using approximate average retail price for small quantities
[4] (Z) Less than 0.5% area applied

Figure 6.5. Map of 2,4-D and MCPA use per state in 2006 reported for in NASS (2015) survey states, expressed as a percent of the area planted. The figure assumes that growers would treat with either 2,4-D or MCPA. The size of the chart is symbolic of the area of winter (WW) or spring (SW) wheat grown in the state.



Barley

Both 2,4-D and MCPA are used for weed control in barley production. About 3.7 million barley acres were treated with 2,4-D in 2011, representing 18% of total barley acres (Table 6.3), which is much less than the 42% of area estimated by the previous effort (Nalewaja 1993). About 37% of the total was treated with MCPA. An estimated 208,000 pounds of 2,4-D were used on barley at 0.43 lb/A, for an annual expenditure of $1.44 million. MCPA use was estimated to be about 284,000 pounds at 0.216 to 0.444 lb/A, depending on formulation, for an annual expenditure of $2.9 million.

Table 6.3. Barley broadleaf herbicide use, including formulations of 2,4-D, in program states1 in 2011.

Herbicides[2]	Area applied	Applications	Rate per application	Total applied	Cost[3]
	%	#	lbs ai per A	1,000 lbs	$ per A
2,4-D, EHE (30063)	11	1.3	0.358	117	2.864
2,4-D, DMA salt (30019)	6	1.4	0.437	88	2.3
2,4-D, ISP salt (30025)	1	2	0.045	3	0.54
Dicamba, dimethylamine salt (29802)	4	1.7	0.087	12	1.20
Dicamba, sodium salt (29806)	1	1.1	0.062	1	6.45
MCPA, 2-ethylhexyl (30564)	32	1	0.337	251	3.20
MCPA, dimethylamine salt (30516)	2	1	0.444	17	4.44
MCPA, isoctyl ester (30563)	3	1	0.216	16	4.4928
Clopyralid (117403)	15	1	0.087	31	6.96
Fluroxypyr 1-MHE (128968)	25	1	0.092	55	7.36
Bromoxynil, heptanoate (128920)	13	1	0.163	51	7.335
Bromoxynil octanoate (35302)	32	1	0.22	163	9.9
Metsulfuron-methyl (122010)	3	1	0.003	(Z)[3]	0.48
Thifensulfuron-methyl (128845)	20	1	0.013	6	1.9409
Tribenuron-methyl (128887)	25	1	0.006	3	1.536

[1] Program states include Arizona, California, Colorado, Idaho, Minnesota, Montana, North Dakota, Oregon, Pennsylvania, South Dakota, Utah, Virginia, Washington, Wisconsin, and Wyoming.
[2] Numbers in parentheses are EPA chemical codes for the active ingredient.
[3] Cost of the herbicide application at the average rate using approximate average retail price for small quantities.

Oat

The most recent use statistics for both 2,4-D and MCPA use in oat are from 2005. At that time, both 2,4-D and MCPA were widely used for weed control in oat production. MCPA was more widely used, being applied to 1.5 million acres or about 14.4% of total oat acres; 2,4-D was used on 1.1 million acres or 10.6% of oat acres (Table 6.4). An estimated 250,000 pounds of 2,4-D were applied each year to oat, at rates ranging from 0.347 to 0.63 lb/A, for an annual expenditure of $1.91 million. MCPA use was estimated to be 103,000 pounds per year, applied at rates ranging from 0.338 to 0.815 lb/A, for an annual expenditure of $1 million.

Table 6.4. Oat broadleaf herbicide use, including formulations of 2,4-D, in program states1 in 2005.

Herbicides[2]	Area applied	Applications	Rate per application	Total applied	Cost
	%	#	lbs ai per A	1,000 lbs	$ per A
2,4-D, EHE (30063)	5	1	0.45	79	3.6
2,4-D, DMA salt (30019)	9	1.1	0.424	147	2.231579
2,4-D, DIETH. Salt (30016)	1	1	0.598	24	5.507895
2,4-D, BEE (30053)	(X)[4]	1	0.347	4	4.3375
2,4-DB, Dimeth salt (30819)	1	1	0.63	12	12.6
Dicamba, dimethylamine salt (29802)	2	1	0.066	5	0.9075
MCPA, 2-ethylhexyl (30564)	4	1.1	0.377	52	3.5815
MCPA, dimethylamine salt (30516)	3	1	0.338	37	3.38
MCPA, sodium salt (30502)	(X)	1	0.815	14	8.15
Clopyralid (117403)	1	1	0.083	2	6.64
Bromoxynil, heptanoate (128920)	1	1	0.224	10	10.08
Bromoxynil octanoate (35302)	1	1	0.236	22	10.62
Thifensulfuron-methyl (128845)	2	1	0.01	1	1.493
Tribenuron-methyl (128887)	2	1	0.005	0.5	1.28

[1] Program states include California, Idaho, Illinois, Iowa, Kansas, Michigan, Minnesota, Montana, Nebraska, New York, North Dakota, Pennsylvania, South Dakota, Texas, and Wisconsin.
[2] Numbers in parentheses are EPA chemical codes for the active ingredient.
[3] Cost of the herbicide application at the average rate using approximate average retail price for small quantities.
[4] (X) Not reported.

Rye

Of the small grain crops, only rye acreage has remained constant since 1991. In 1991, about 12.3% or 218,000 acres of rye were treated each year with about 124,000 pounds of 2,4-D at a rate of about 0.57 lb/A (Nalewaja 1993). Although no recent use data is available, it is likely that the use pattern in rye is similar to that of oat, with a small proportion of the total acreage treated with 2,4-D or MCPA.

Phenoxy Herbicide Registration Summary

The phenoxy herbicides 2,4-D and MCPA applied at 0.25 to 1.4 lb/A are registered for broadleaf weed control in wheat, barley, oat, and rye (Table 6.5). The 1.4 lb/A rate is for emergency perennial broadleaf weed control in wheat and as a harvest aid in wheat, barley, and oat. Individual labels differ as to rates for the small grains. Oat is more susceptible than the other small grains to phenoxy herbicides, and use in oat is limited.

Table 6.5. Herbicides and their registrations used for broadleaf weed control in small grains in the United States. An '*' indicates herbicide use data reported by NASS (2015).

	Small grain			
Herbicide	Wheat*	Barley*	Oat*	Rye
Aminopyralid	R			
Bromoxynil*	R	R	R	R
Chlorsulfuron	R	R	R	
Clopyralid*	R	R	R	
2,4-D*	R	R	R	R
Carfentrazone*	R	R	R	R
Dicamba*	R	R	R	
Diuron	R			
Florasulam*	R	R		
Fluroxypyr*	R	R	R	
Glyphosate*	R	R	R	R
Imazamethabenz	R	R		
Imazamox*	R			
Linuron	R			
MCPA*	R	R	R	R
Metribuzin*	R	R		
Metsulfuron*	R	R		
Paraquat*	R	R		
Pendamethalin*	R			
Picloram	R	R	R	
Prosulfuron*	R	R	R	R
Pyraflufen*	R			
Pyrasuflotole	R	R		R
Pyroxsulam*	R	R		
Thifensulfuron*	R	R	R	
Triasulfuron*	R	R		
Tribenuron*	R	R		
Trifluralin*	R	R		

Losses from Broadleaf Weeds

Small grains can be competitive with weeds, although certain species can cause significant yield loss if left untreated. Broadleaf weed competitiveness with small grains also depends on cultural inputs such as seeding rate, planting and emergence dates, availability of soil nutrients, moisture, temperature, and other factors (Dahl 1980; Friesen and Shebeski 1959; Nalewaja 1972; Swinton et al. 1994). Common broadleaf weeds in wheat vary by region. In the Pacific Northwest, prickly lettuce, mayweed chamomile, Russian thistle, and mustard species are dominant. In the Great Plains, blue mustard, henbit, flixweed, field pennycress, and shepherd's- purse are problematic (Reddy et al. 2012), while in the mid-Atlantic and southern states, henbit, chickweeds, wild mustard, wild radish, and cutleaf evening primrose are weeds of concern (Webster and Nichols 2012).

A variety of over 20 other broadleaf weeds impact the growth of small grains (Nalewaja 1970; Reddy 2012; Webster and Nichols 2012). Applied at the proper time, 2,4-D controls or suppresses many of these weeds; however, it does not control mallow, common milkweed, yellow woodsorrel, some smartweeds, fumitory, false chamomile, or nightflowering catchfly. Usually several weed species occur in a single field, so 2,4-D or other phenoxy herbicides are important components in tank mixtures with other herbicides in order to achieve broad-spectrum weed control (Nalewaja 1996).

Although broadleaf weeds can cause yield loss, density dependent data on loss due to interferences is limited to only a few species, as yield loss trials have primarily emphasized grass weeds. Density dependent yield loss for broadleaf weeds in small grains can be quite variable. For instance, in unpublished work conducted in North Dakota, wild mustard at 140 plants per yd caused a 30% wheat yield loss, but the same number of wild buckwheat plants caused only a 10% yield loss. In an additional study, wild mustard populations of 36 to 133 plants per yd caused an average 29% yield loss (Dahl 1980). Wheat yield losses of 21% to 50% from 152 plants per yd were observed in five experiments conducted over 2 years (Bell et al. 1972). Crop yield loss associated with henbit or common chickweed interference ranged from 0.3 to 48% based on weed density (Farahbakhsh et al. 1987; Northam et al. 1993). Additional work by Conley and Bradley (2005) noted that henbit at 22 plants per yd did not reduce wheat yield but yield loss at 98 and 185 plants per yd was 13 and 38%, respectively. By comparison, blue mustard is much more competitive with wheat than the previously discussed species - yields were reduced from 28 to 51% by populations of 12 to 116 plants per yd (Swan 1971). Information on competition from various densities of perennial broadleaf weeds in small grains paint a similar picture. Canada thistle at 4 plants per yd caused a 17% yield loss in wheat (Hodgson 1968), and field bindweed at 10 plants per yd caused an 18% yield loss (Gigax 1978).

Winter and spring wheat are regarded as the least competitive small grains. Oat, rye and barley are sufficiently competitive that a significant proportion of the acreage is not treated with herbicides (Figures 6.1 thru 6.4). Thus, there is disagreement about the benefit of treating broadleaf weeds in wheat that is ultimately reflected in the regional use patterns of herbicides (Figure 6.5). Scott et al. (1995) and Mertens and Jansen (2002) declared that control of winter annual broadleaf weeds, such as henbit or common chickweed, may not be beneficial in the central Great Plains. However, continued use of broadleaf herbicides by growers is indicative that control is crucial for crop protection. In the central Great Plains, acreage treated with a herbicide has varied between 60 and 90%. By contrast, >90% of the winter and spring wheat in the Pacific Northwest and the spring wheat in North Dakota is treated with a broadleaf herbicide every year (Figure 6.5).

Yield Protection from Herbicides Used to Treat Broadleaf Weeds

Yield protection afforded to a grower by herbicides can be substantial, though also species dependent. Grower net return ranged from $13.25 to $21.99/A when henbit and common chickweed were effectively managed in winter wheat (Vrabel 1987). Wild mustard can cause significant yield loss, but that yield loss was reduced to 13% by a post-emergence treatment with 2,4-D at0.25 lb/A. Wild mustard control from 2,4-D varied from 48 to 100% population reduction, and surviving wild mustard plants were severely injured but still green at harvest. Even though 2,4-D did not completely kill all wild mustard, yields of treated wheat equaled that of wheat which was hand weeded at the time of spraying, indicating that 2,4-D was not injurious to wheat (or was substantially less injurious than the weed competition) and that the 13% yield loss was from wild mustard competition prior to herbicide treatment.

Kochia is a problematic and highly competitive weed in wheat in the Great Plains small grain growing area. Interference with small grains caused by kochia is usually severe. In experiments evaluating the efficacy of various herbicides for kochia management, 2,4-D at 0.5 lb/A gave 88% to 100% kochia control and increased wheat yield an average of 142% (Bell et al. 1972). By comparison, bromoxynil at 0.25 lb/A increased wheat yield 140% and dicamba at 0.12 lb/A increased yield 139%. Among the three treatments, 2,4-D (as a DMA salt, Table 6.1) remains the least expensive treatment for kochia management, although resistance to 2,4-D and dicamba has become common in the north central Great Plains (Nandula and Manthey 2002).

In general, oat, barley and rye are regarded as more competitive with weeds than wheat, and thus herbicides would likely return incrementally lower yield protection as a consequence. Grasses are not controlled by 2,4-D, and it does not control all broadleaf weed species, but 2,4-D reduced weed related losses from 14% to 6% in 142 wheat fields with a mixture of weed species over 3 years in Manitoba (Friesen and Shebeski 1959).

Current Control Methods

Chemical Weed Control

Herbicides applied post-emergence are the most common method of broadleaf weed control in small grains. Tillage is used to control weeds during seedbed preparation and after harvest. Small grains are seeded in rows, usually less than 32 cm apart. Specialized approaches exist on a regional basis, but cultivation during the growing season is not widely practiced in conventional small grain production. Thus, selective herbicides are essential to small grain production.

Nonselective herbicides have for the most part reduced or eliminated the need for tillage prior to planting and thus facilitate timely crop seeding. Timely seeding in the spring is essential to optimize small grain yields, and timeliness is often more important to yield than controlling weeds (Dahl 1980; Blue et al. 1990). Large equipment for tillage and seeding have made timely seeding of large acreages possible. The practice of delayed seeding of spring-sown small grains, which employed tillage to stimulate weed seed germination and subsequent tillage to control the emerged weeds, is no longer a general practice and has been replaced by one or more applications of glyphosate or paraquat.

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The long list of herbicides registered for broadleaf weed control in small grains indicates the importance of weeds, the dependence of growers on herbicides for weed management, and the diversity of weeds in small grains throughout the US (Table 6.5). Some of the herbicides listed are specifically for grass weed control, but they may also control certain broadleaf weeds. For example, pyroxsulam controls wild mustard even though it is used mainly for Italian ryegrass, downy brome, and wild oat control. Sulfonylureas, bromoxynil, florasulam, fluroxypyr, clopyralid, and dicamba are usually used in combination with a phenoxy herbicide to increase the weed control spectrum and crop safety as well as to reduce the potential for weed resistance.

Trifluralin, pendimethalin, and metribuzin are used for grass weed control in small grains, but they also control certain broadleaf weeds. In general, their use is not common, as growers have moved away from pre-emegence herbicides.

Certain herbicides are restricted to specific small grain cultivars or certain growing regions. Chlorsulfuron is restricted to areas with relatively low pH soils to reduce crop damage from carryover, and was most commonly used in areas with wheat-fallow rotations. Diuron and metribuzin are restricted to only winter wheat grown under specific climate conditions.

Glyphosate and paraquat give broad-spectrum weed control prior to seeding or emergence of small grains, and thus are used as a substitute for tillage.

An additional factor for herbicides in small grain production is the discovery and use of herbicide safeners. Cloquintocet-mexyl and mefenpyr-diethyl are now an integral part of many herbicide products and enable the selective use of ACCase, ALS, and HPPD inhibitors safely for broadleaf and grass weed control. It has led to the proliferation of multiple products containing the same active ingredients, but with different safener loads.

Mechanical Weed Control

Hand pulling of weeds in small grains was a common practice prior to the introduction of the phenoxy herbicides in 1945 (Timmons 1970). However, present labor costs make hand pulling of weeds in small grains economically unfeasible. Furthermore, the drudgery of pulling weeds and the difficulty of accessing narrow rows is not readily accepted by laborers. In general, only particularly damaging weeds are hand pulled at great expense, including jointed goatgrass and cereal ryegrass in winter wheat. Hand hoeing for broadleaf weed control in small grain fields seeded in 6-inch rows would be difficult and unacceptable because of the damage to the crop from the hoe and hoer. Furthermore, weeds growing within the crop row might not be destroyed by hoeing, and yield losses would still occur.

Plowing and disking were common practice for weed management in wheat in the early 1900's (Schillinger 2008; Smika 1990). Both primary and secondary tillage have declined since the introduction of 2,4-D and selective herbicides in general, and there is now significant acreage of conservation and no-tillage systems throughout wheat production areas. These systems are dependent on herbicides and particularly on glyphosate and 2,4-D.

Cultural Weed Control

Rotation of crops having a different life cycle than small grains is practiced in areas with adapted marketable crops. Crops with an optimum seeding date later than small grains also allow for control of early weed flushes by tillage or herbicides prior to crop seeding. Increased seeding rate is known to increase the competitiveness of small grain stands as well. In general, the most effective rotational crop with small grains is one with a different life cycle (winter vs. spring) or a broadleaf crop. Small grain production areas often utilize pulses such as chickpea, lentil, and peas. Also common is the wheat-fallow rotation. In each case, weed management in rotation often includes rotation of herbicide mode of action, change of timing of the herbicide application, or other shifts away from the timings found in small grains production.

Cost of Control Methods

The cost for various herbicides for broadleaf weed control in small grains varies depending on crop (Tables 6.2, 6.3, 6.4, and 6.5). Phenoxy herbicides, 2,4-D and MCPA are the lowest priced of those herbicides that are often applied alone. Only the sulfonylurea herbicides were less expensive, primarily

> *The cost for hand pulling wild mustard from an acre of land varies significantly depending on weed density, but is at least $23.00 per acre, compared to 2,4-D's $2.00 per acre.*

because they are applied in mixture with phenoxy herbicides.

The cost of controlling weeds using methods other than herbicides is not feasible. As Nalewaja (1993) reported (and using standard units for ease of comparison), hand pulling wild mustard requires ~2 hours/A walking and looking and an additional pulling time of 1.4 to 4.0 seconds per plant, with time per plant decreasing as density increased to

450,000 plants/A (Dexter 1982). The cost for hand pulling wild mustard from an acre of land varies from $23.00 for 5,000 weeds removed to $1,629.44 for 435,000 plants/A (when adjusted for inflation). Thus, 2,4-D at about $2.01/A (for just the DMA salt, applied at the national average use rate of 0.382 lbs ai/A) would be much less costly than the $23.01/A to hand pull a low wild mustard infestation of only one plant per yd. Hand hoeing is not practical in small grains, but required 97.5 hours/A for wild oat removal (Nalewaja 1980), which is slightly greater than what would be required for removal of a tap-rooted broadleaf weed.

Fallow is practiced for moisture conservation and weed control in the drier small grain producing regions of the US. The practice of fallowing in small grain rotations has effectively reduced weed densities (Somody et al. 1980). However, the cost of not producing a crop plus the cost of tillage during the fallow year may be economically devastating to the grower. Conventional fallow still consists of up to 5 field cultivations per year to control weed growth (Jensen 1969; Janosky et al. 2002). Chemical fallow uses herbicides such as glyphosate, paraquat, dicamba, and 2,4-D to manage weeds without soil-eroding or moisture depleting cultivation. Regardless of system, fallow management is inherently inefficient because moisture loss is significant during the fallow year.

Herbicide Alternatives If 2,4-D Were Lost

MCPA would be the primary alternative were applicators to lose access to 2,4-D. MCPA is used in all small grains, as it is less injurious than 2,4-D. MCPA is less effective than 2,4-D on many weeds, such as Russian thistle, kochia, wild buckwheat, and redroot pigweed. Thus, MCPA would require application in combination with other herbicides or at higher rates if used alone. Replacement of 2,4-D by MCPA in combination with other herbicides would control most weeds in wheat, particularly pyrasulfotole. However, on a per acre basis, no herbicide controls as many weeds as inexpensively as 2,4-D. The loss of only 2,4-D probably would not reduce grain yields greatly, but it would increase the cost of weed control and allow more rapid development of weed resistance to other herbicides.

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Impact of the Loss of 2,4-D

In 1993, Nalewaja reported that when weed specialists were questioned about banning 2,4-D in wheat and barley production while leaving other phenoxy compounds available, they indicated that such a ban would cause growers to substitute MCPA on 77% of the area currently treated with 2,4-D. Both dicamba and bromoxynil would each be used on 8% of the area currently treated with 2,4-D (Nalewaja 1993). Since the early 1990's, patent protection has expired for a number of herbicides, and there is now widespread resistance to the sulfonylurea herbicides. The use of 2,4-D is in decline in wheat and barley (Figures 6.1, 6.2, and 6.3) and MCPA is not used in the southern Great Plains, where a majority of wheat is not treated with a herbicide at all (Figure 6.4). In the northern Great Plains and the Pacific Northwest, loss of 2,4-D would likely cause an increase in the use of MCPA, although clopyralid plus fluroxypyr or pyrasulfotole plus bromoxynil based programs are more likely options. The use of 2,4-D in spring wheat is much lower than winter wheat, and most spring wheat is treated with bromoxynil (Table 6.2). Overall use of 2,4-D has been declining in wheat and barley, and the use of clopyralid and fluroxypyr has increased (Figures 6.1, 6.2, and 6.3).

Banning 2,4-D but allowing other phenoxy herbicides to remain in use would cause most oat and rye growers to shift to MCPA. Bromoxynil is really the only other effective affordable option for use in oat and barley, and there are not many options for 2,4-D alternatives for oat and rye like there are for wheat and barley. Growers of oat and rye would likely choose to withhold treatment and as a consequence and suffer greater losses due to weeds.

Herbicide Alternatives and Impacts If All Phenoxy Herbicides Were Lost

Alternatives to phenoxy herbicides could adequately control most broadleaf weeds in small grains, but at a greater cost. When the original review of the utility of 2,4-D was published, metsulfuron was identified as the primary non-phenoxy alternative for wild mustard management for which phenoxy herbicides are applied alone. In the early 1990's metsulfuron would increase control cost by $2.03/A. In the last 20 years, widespread resistance to metsulfuron, thifensulfuron, and tribenuron, coupled with a loss of patent protection, has significantly decreased the value of these herbicides. Even though metsulfuron can now be applied for an average of $0.48 per A, it is not a viable alternative to 2,4-D for control of many broadleaf species.

Clopyralid, fluroxypyr, and dicamba are viable alternatives for phenoxy herbicides, although they are also growth regulating herbicides. They are all no longer under patent protection and are more affordable, but are still more expensive than the phenoxy herbicides (Table 6.1).

Bromoxynil continues to see widespread usage in small grains, particularly spring wheat (Table

6.2). It is usually applied in mixture with MCPA for control of small broadleaf weeds. Bromoxynil use without MCPA is limited; an alternative herbicide would have to be identified for use in mixture with bromoxynil to increase the spectrum of weeds controlled. Bromoxynil is also used as a synergist with newly introduced herbicides that inhibit carotenoid biosynthesis, like pyrasulfotole. However, bromoxynil is applied at sublethal rates in such mixtures.

The newest broadleaf herbicides for use in small grains are carotenoid biosynthesis inhibitors, the foremost being pyrasulfotole. As a new product, it is expensive relative to phenoxy herbicides, but is effective for management of many of the broadleaf species controlled by phenoxy herbicides. Unfortunately, no use data could be identified for pyrasulfotole.

Overall, the impact of the loss of all phenoxy herbicides would be substantial. The phenoxy herbicides are cost-effective herbicide inputs in an era of rising costs for growers. Alternative herbicide inputs are more expensive, and for crops of limited value or for areas with limited yield potential, not viable for small grains production.

Weed Resistance Management

Phenoxy herbicides are integral in managing herbicide resistance development in small grains. Many weeds have developed resistance to ALS-inhibiting herbicides. However, the phenoxy herbicides are not immune to resistance development. Kochia, a highly competitive weed with small grains, is not always controlled by phenoxy herbicides. Kochia developed resistance to dicamba in addition to glyphosate and ALS inhibitors - primarily because growers persisted in utilizing a single mode of action. Phenoxy herbicides are incorporated into resistance management schemes to delay the development of weed resistance to multiple modes of action primarily because they are effective and affordable. The availability of 2,4-D is important for use in herbicide mixtures or in herbicide rotation as part of resistance management systems.

> *Overall, the impact of the loss of all phenoxy herbicides would be substantial. The phenoxy herbicides are cost-effective herbicide inputs in an era of rising costs for growers. Alternative herbicide inputs are more expensive, and for crops of limited value or for areas with limited yield potential, essential for small grains production.*

Compelling Reasons to Retain Phenoxy Herbicides in Small Grains

1. *Phenoxy herbicides economically control many important broadleaf weeds in small grains.*
2. *Phenoxy herbicides have been used widely, without adverse effects to humans and the environment, for 70 years.*
3. *Weeds generally have not developed resistance to phenoxy herbicides even after 70 years of usage, except in rare circumstances. When resistance has occurred, it has not diminished the utility of the phenoxy herbicides.*
4. *Phenoxy herbicides are important components of weed resistance management, either in mixtures with other herbicides or as separate applications in alternate years.*
5. *The small grain acreage treated with herbicides would decrease and yields would be reduced if the phenoxy herbicides were lost. The production areas that would be most affected by a loss of phenoxy herbicides are low yielding areas that are really only suitable for the production of wheat, oat, and rye.*
6. *If phenoxy herbicides were lost, fallow and more intensive tillage would increase with accompanying soil losses to erosion by wind and water.*
7. *Phenoxy herbicides are especially effective on specific weeds that need to be controlled in IPM programs based on crop rotation.*

The Future of Weed Management in Small Grains

Phenoxy herbicides, because of their long history of usage without any known adverse environmental effects, are accepted components of most agricultural systems. Alternatives to phenoxy herbicides are more costly, more prone to resistance development, or have less favorable toxicological profiles, which has limited their acceptance in small grains weed protection systems. The primary goal of future weed management will be to use various control practices, including herbicides, to minimize costs to the producer while eliminating or reducing adverse effects to the environment. The phenoxy herbicides 2,4-D and MCPA are highly effective at controlling many weed species in small grains. Controlling weeds in small grains have reduced their occurrence in subsequent crops. Phenoxy herbicides are essential components of small grain production systems, when used alone or in mixture with other herbicides. In combination with tillage and cropping practices, they are crucial for inexpensive, effective weed control and herbicide resistance management.

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