

# Glyphosate Resistant Weeds: Educational Materials and Initiatives to Address Glyphosate Stewardship

Bill Johnson

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# Primary Pest Problem Perceptions of Indiana Farmers

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Percent of farmers who considered each pest to be the primary pest in corn and soybean

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Weeds	78 (1.6)
Insects	8 (1.0)
Disease	8 (1.4)
Nematodes	6 (0.9)

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# Level of Concern About Glyphosate Resistance Among Indiana Farmers

Farm size	High	Moderate	Low or not concerned	Usable responses	Total number of Indiana farms in this size category	Usable responses from this size category
Hectares		%		no.	no.	%
199 or less	34	46	19	249	51,985	0.5
200 to 399	32	47	20	81	4,949	1.6
400 to 799	35	46	18	65	2,827	2.2
800 or more	40	44	16	25	990	2.5
Mean (SD)	36 (3)	46 (1)	19 (2)	--	--	--

# Factors that Contribute to Weeds Developing Resistance to Glyphosate According to Indiana Farmers

Farm Size	Repeated use of same mode of action	Poor application technique or timing	Unique weed characteristics	Changes in tillage practices	Usable responses
Hectares		%			no.
199 or less	59	31	8	2	217
200 to 399	62	36	9	3	94
400 to 799	60	36	3	0	71
800 or more	51	37	11	0	36
Mean (SD)	58 (5)	33 (5)	8 (4)	1 (2)	

# Weed “Management” in Soybean



When did glyphosate stewardship and resistance management become a regional effort?

Several industry meetings between 2001 and 2005

- At length discussions of glyphosate use, abuse and control of problem weeds
- In 2005 we established an informal “Glyphosate Stewardship Working Group”
  - ½ day meeting in Indianapolis in March 2005
  - ½ day meeting in Des Moines in September 2005

# Glyphosate Stewardship Working Group

- Printed educational materials
  - Glyphosate stewardship
    - Herbicide management to avoid resistance
    - Economic implications of stewardship
  - Biology and management of specific weeds
    - Horseweed
    - Wild buckwheat
    - Common lambsquarter
    - Giant ragweed
    - Common ragweed
    - Waterhemp
  - 300,000 copies at \$0.27/copy = \$81,000

# Glyphosate Stewardship Publications

- Challenges
  - Time
  - Money
    - BASF
    - Bayer
    - DowAgroSciences
    - Dupont
    - Monsanto
    - Syngenta
    - Valent
    - \$48,000 promised – \$31,000 delivered so far
    - NCIPM Competitive Grants Program – \$35,000
    - Total = \$83,000

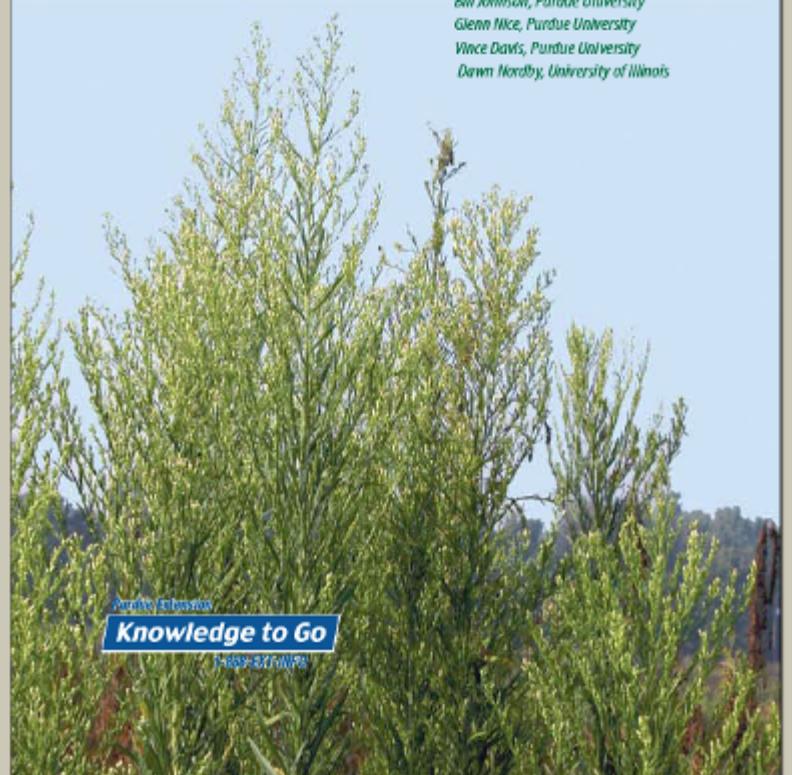
# Glyphosate Stewardship Working Group

- Printed educational materials
  - Glyphosate stewardship
    - Herbicide management to avoid resistance (2005 or 2006)
    - Economic implications of stewardship (2006)
  - Biology and management of specific weeds
    - Horseweed (2005, revised in 2006)
    - Wild buckwheat (2006)
    - Common lambsquarter (2006)
    - Giant ragweed (2007)
    - Common ragweed (2007)
    - Waterhemp (2007)
  - Others
    - Value of soil-applied herbicides (2006)
    - Glyphosate application methods (2006)

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# Biology and Management of Horseweed

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## Glyphosate, Weeds, and Crops

flowers (1/16 to 1/16 inches long) and 20 to 40 yellow disk flowers (see Figure 1). The seeds are small achenes (1/16 to 1/4 inches long), with a pappus of tan to white bristles. A pappus is a structure that allows the seed to be dispersed by the wind, similar to that of common dandelion.

Horseweed (see Figure 2) is often misidentified as whitlowgrass, mouseear chickweed, corn or Persian speedwell, shepherd's-purse, or several of the fleabane species, especially annual fleabane (see Figure 3). The two most common misidentifications are whitlowgrass and fleabane species. Whitlowgrass has shorter



Figure 2. This photo shows a horseweed seedling in rosette stage, just beginning to bolt.



Figure 3. The photos above show weeds commonly confused with horseweed: whitlowgrass (top left), mouseear chickweed (middle left), annual fleabane (bottom left), corn or Persian speedwell (top right), and shepherd's-purse (bottom right).

## Biology and Management of Horseweed — GWC-9

and narrower leaves than horseweed, and a smooth to very slightly notched margin. Around the leaf margin, annual fleabane tends to have purple spots at the tip of each tooth while horseweed does not have these spots. Also, the distance between nodes on all fleabane species after bolting are greater than the internode distance on horseweed. Fleabanes will produce more branches than horseweed at the base of the plant. Mouseear chickweed, and corn and Persian speedwell have opposite leaves at all early stage nodes, and can easily be separated from horseweed, which has alternating leaves at all nodes. The first node of shepherd's-purse tends to have opposite leaves while subsequent nodes have alternate leaves, although leaves at all nodes may be alternating. The hairs on shepherd's-purse leaves are shorter and tend to stay on the upper leaf surface compared to horseweed leaf hairs, which are larger and usually present on leaf margins. In later development stages, shepherd's-purse leaves will be deeply lobed compared to the toothed or slightly lobed leaves of horseweed.

## Distribution and Emergence

Horseweed seed germinates readily as soon as it falls off a mature plant. Horseweed plants usually germinate in the fall or spring, but they also can germinate in midsummer if growing conditions are adequate. In northern regions of Indiana, Illinois, and Ohio most horseweed emerges in the fall, overwinters as a rosette, and begins to bolt in the spring. Typically, up to 91 percent of fall-emerging plants survive until spring. This broad survival range can be attributed to weather conditions and the size of the horseweed rosette. The larger the rosette is prior to winter, the greater the chance of survival into the spring (Buhler and Owen 1997). Horseweed emerges predominately in the spring in the southern regions of Indiana, Illinois, and Ohio. In southeast Indiana and southwest Ohio, spring germinating horseweed is one of the most problematic summer annual weeds. Spring horseweed generally remains a rosette for a relatively short period prior to bolting. Horseweeds germinating in July and August tend to remain as rosettes until the following spring, with only a few plants bolting and producing flowers in the fall.

## Growth and Development

Following rosette formation, horseweed plants begin bolting in mid-April and start flowering at the end of July. Horseweed is self-compatible and releases pollen before the capitula are fully opened, supporting the idea that horseweed is primarily self-pollinating; however, outcrossing within a population has been observed to range from 1.2 to 14.5 percent. Horseweed's wind dissemination and relatively abundant seed production suggests that the dispersal of resistant horseweed plants across an agricultural landscape could be very rapid. Regahr and Bazzaz (1979) reported that horseweed seed movement in a corn field ranged from 12,500 seeds per square yard at 20 feet from the seed source, to more than 125 seeds per square yard at 400 feet from the seed source. Taller plants produce more seed than shorter plants, suggesting that seed height on plants might influence both the distance wind can transport seed and the total number of seeds that are transported.

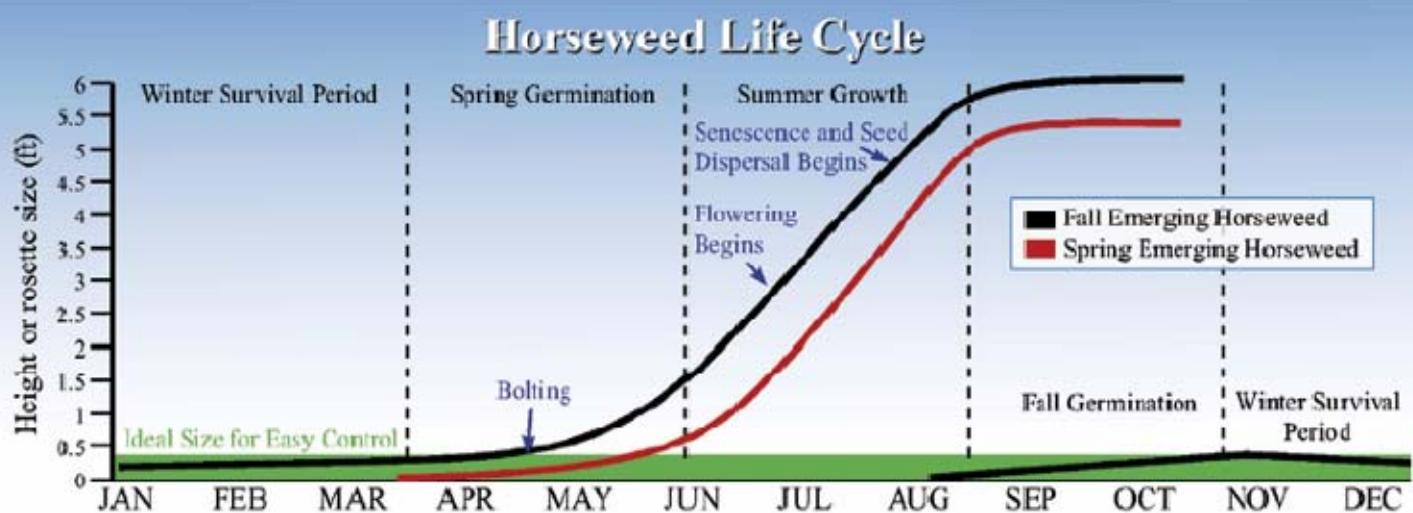


Figure 4. This graph shows the relative life cycles of horseweed throughout the year for plants that emerge in the spring and fall.

## Interference and Competition

In southeast Indiana and southwest Ohio, horseweed often behaves like a summer annual. In these situations, horseweed begins to emerge from late March into late June. Southeast Indiana soils characteristically have a shallow layer of silt over a thick clay layer. These soils have relatively poor internal drainage and water holding capacity and require frequent light rains to maintain optimal crop growth. Horseweed tolerates drought conditions well and continues to grow and produce biomass and seed under conditions stressful for crop growth. Horseweed can produce up to 200,000 seeds per plant, and approximately 80 percent of the seed will germinate right off the plant. Because of the unique soils in this region and widespread adoption of no-till practices, horseweed has emerged as the number one weed problem in this area.

Bruce and Kells (1990) showed in management studies conducted in Michigan that soybean yields could be reduced up to 83 percent by horseweed in untreated check treatments. In general, we feel horseweed is much less competitive than most of the other summer annual weeds. However, no traditional competition studies have been published that have evaluated the effect of density or emergence time on its capability to reduce soybean and corn yields. We do know that horseweed can affect crop production in ways besides direct competition for light, water, and nutrients. Horseweed can be a host for the tarnished plant bug, an alfalfa pest. It can also be a host for aster yellows, a viral disease transmitted by aster leafhoppers to a wide variety of plants.

## Increased Prevalence

Three factors are commonly mentioned as the causes of increased horseweed prevalence: lack of diversity in crop rotation, reduced tillage, and herbicide resistance.

### Crop Rotation

Crop rotation appears to have a minimal impact on horseweed prevalence. In field surveys conducted in areas where horseweed was most problematic in Indiana, horseweed was found in 63 percent of double crop soybean fields, compared to 51 percent in continuous soybean fields, and 47 percent in fields in a corn-soybean rotation.

### Tillage

In the same survey mentioned above, increases in tillage intensity reduced horseweed prevalence by 50 percent or more. Horseweed was found in 61 percent of the no-till fields compared to 24 percent in reduced tillage and 8 percent in conventional tillage fields.

### Herbicide Resistance

Japanese researchers reported the first case of horseweed herbicide resistance in 1980, describing biotypes resistant to Gramoxone® (paraquat). More Gramoxone®-resistant biotypes have since been found in Mississippi. The second case of resistance was reported in 1989 by researchers in Belgium, who found biotypes resistant to atrazine in corn, nurseries, and roadsides. Additional atrazine-resistant biotypes have since been found in Michigan. ALS-resistant horseweed biotypes were first found in the United

## Glyphosate, Weeds, and Crops

States in Indiana and Ohio during the 1999 growing season, and today are believed to be present in all Ohio counties west of Interstate 71 and U.S. Route 23.

Biotypes resistant to glyphosate (which is sold under the trade names Roundup®, Touchdown®, and others) were first reported in Delaware in 2000. Since 2000, glyphosate-resistant biotypes have been found in several additional states. In Indiana, glyphosate-resistant biotypes have been found in 29 counties, mostly in the southeast. However, glyphosate-resistant horseweed has been found as far north as Kosciusko County in northern Indiana and Montgomery County in the west-central area. In Ohio, glyphosate-resistant biotypes have been found in 20 counties, mostly in southwestern Ohio but now stretching to northwest and central Ohio.

Glyphosate-resistant horseweed populations in Ohio and Indiana were first reported in areas where the following production practices are common: soybeans grown in the same field for consecutive years (up to 14 years in some fields), use of only glyphosate for weed control, and little or no tillage.

In horseweed, resistance to more than one herbicide has been reported in Israel with a biotype resistant to atrazine and Glean® (an ALS inhibitor); in Michigan with a biotype resistant to atrazine, simazine, and diuron; and in Ohio with a biotype resistant to glyphosate and FirstRate® (an ALS inhibitor) in 2003. The glyphosate and FirstRate® resistant biotype in Ohio has been confirmed in at least two fields (one each in Montgomery and Miami counties) and appears to be spreading. We assume that these biotypes are also resistant to other ALS inhibitors, such as chlorotoluron (Classic®, Canopy®, Synchrony®).

In Indiana, horseweed populations resistant to glyphosate and FirstRate® have been found in Bartholomew, Jefferson, Scott, and Washington counties; populations resistant to glyphosate and Classic® have been found in Bartholomew, Scott, and Wells counties; and populations resistant to glyphosate, FirstRate®, and Classic® have been found in Bartholomew and Scott counties.



Figure 5. Glyphosate-resistant horseweed has been identified in at least one field in the counties marked with solid orange. A few fields contain horseweed populations resistant to glyphosate and either chlorotoluron or lorasulam — these counties are indicated with the crosshatch pattern.



Figure 6. Other horseweed populations showing resistance to ALS and glyphosate herbicides (top row), resistance to glyphosate herbicide only (second row from top), resistance to ALS herbicide only (third row from top), and no herbicide resistance (bottom row).

## Control

The primary goal of a horseweed management program in no-till soybeans should be effective control of emerged horseweed plants prior to planting. Soybeans planted before early to mid-May also will require a residual herbicide to control later emerging plants. This strategy will reduce the need for postemergence herbicide treatments, which can be limited in effectiveness and exert further selection for herbicide resistance in the population. The following principles are important in horseweed control programs:

- 2,4-D ester should be included in preplant herbicide treatments when possible.
- Herbicides should be applied before horseweed plants are 4 to 6 inches tall.
- Herbicides applied in the fall will control emerged horseweed, but may not adequately control spring-emerging plants.
- Spring applications prior to early May should include a residual herbicide to control later-emerging plants.

## Control of Emerged Plants Before Planting

Treatments containing fewer than three herbicides may be less effective on an ALS-, glyphosate-, or multiple-resistant population. Chlorimuron is a component of Canopy EM®, Canopy®, and Symphony XP®; and diclosulam is a component of FinistRate®, Amplify®, and Gangster®. The most effective treatments for controlling horseweed plants up to about 6 inches tall are roughly ranked in order of effectiveness:

- A combination of glyphosate and 2,4-D ester; plus chlorimuron or diclosulam
- A combination of glyphosate and 2,4-D ester
- A combination of Sencor®, Gramoxone®, and 2,4-D ester
- A combination of glyphosate plus chlorimuron or diclosulam

## Glyphosate, Weeds, and Crops

Several other treatments can be effective when plants are less than two inches tall, including: Sencor® plus 2,4-D ester; Sencor® plus Gramoxone®; and 2,4-D ester alone. A combination of 2,4-D ester plus chlorimuron or diclosulam can also be used on small plants, but effectiveness will be reduced in ALS-resistant populations. The minimum glyphosate rate should be 1.1 lbs. ac/A for all biotypes. Dixamba is better suited to southern areas of the country because warmer weather will speed the degradation of the herbicide so it is less likely to injure soybeans. It is important to remember that when dicamba is applied at 0.25 lb. ac/A, growers must wait 12 days after application and receive at least one inch of rain before planting soybeans.

### Residual Horseweed Control (Spring Application)

In fields where horseweed may be ALS-resistant, the most effective herbicides include Gangster®, metribuzin (at least 0.4 lb. ai/A), sulfentrazone, and Valor®, Canopy EM®, FinistRate®, Amplify®, or Gangster®, or Pytho® can be used for residual control in fields where the horseweed is not ALS-resistant.

### Spring Herbicide Recommendations

Based on Horseweed Size

#### Fields Treated With Herbicide the Previous Fall

Fields should be free of overwintering horseweed in the spring, as long as 2,4-D-ester was a component of the fall treatment, but additional horseweed emergence is likely. It is possible that residual herbicides applied in the fall, such as Canopy EM®, Valor®, and Sencor®, can control horseweed through early June. This is most likely to occur in smaller populations that are not ALS-resistant. Regardless of the herbicide(s) applied in fall, fields should be scouted before planting. Apply herbicide as needed prior to soybean planting to control emerged horseweed, and include residual herbicides if the field is planted before mid-May.

#### Horseweed in the Seedling or Rosette Stage (April)

Controlling horseweed in the seedling or rosette stage can be extremely effective since small plants are easily controlled and residual herbicides applied at these stages can provide control through early June. Emerged plants should be adequately controlled by 2,4-D ester (1 lb. ai/A). When the 2,4-D rate is limited to 0.5 lb. ai/A, combine with glyphosate, Sencor®,



Figure 7. Horseweed plants surviving through soybean canopy in late summer.

or Sencor® plus Gramoxone®, Sencor® plus Gramoxone® (without 2,4-D) can effectively control seedlings or small rosettes.

#### Horseweed Stem Elongated But Not More Than 4 to 6 Inches Tall (May)

During this stage, the most effective treatment is glyphosate, plus 2,4-D ester, plus chlorimuron or diclosulam. Glyphosate plus 2,4-D ester is effective where glyphosate resistance is not an issue; and glyphosate, plus either chlorimuron or diclosulam is effective where ALS resistance and ALS plus glyphosate resistance is not an issue. Use a glyphosate rate of at least 1.1 lb. ac/A, unless ALS and glyphosate resistance is present, then use a minimum rate of 1.5 lbs. ac/A. Somewhat more variable, but generally effective on this size plant, is the combination of Sencor® plus Gramoxone® (minimum of 1.7 pt./A) plus 2,4-D ester.

#### Horseweed More Than 6 Inches Tall (Mid- to Late May)

Horseweed of this size will likely be difficult to control. Anything less than a three-way mixture of glyphosate plus 2,4-D ester, plus chlorimuron or diclosulam, is not recommended. Use a glyphosate rate of at least 1.5 lbs. ac/A. Resistance to glyphosate and/or ALS inhibitors can result in situations where effective control is not possible.

## Conclusion

Weed resistance is not new to agriculture; we have been dealing with it for some time. Awareness and prevention are the first steps to dealing with this problem. As with other weed resistance issues, dealing with resistant horseweed requires adjusting management strategies. Having knowledge of herbicide groups and using combinations of herbicides with different modes of action will help decrease additional resistance problems from arising.

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# Biology and Management of Wild Buckwheat

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## Identification

Wild buckwheat is a summer annual that grows from a hard, black, triangular seed about 1/8 inch long (see Figure 2). The cotyledon is narrow with a rounded tip and base. The plant has long, slender, creeping stems that trail along the ground or climb any plants or objects they contact (see Figures 1 and 3). The leaves are alternate, heart- or arrowhead-shaped, pointed at the tip, and have widely separated lobes at the base (see Figure 4). Plants bloom throughout the summer and the flowers are small and have no petals, but have five greenish or pinkish sepals. Flowers are located in short-stemmed clusters in the axils of the leaves or at the end of stems (see Figure 5).



Figure 2. Wild buckwheat grows from hard, black, triangular seeds about 1/8 inch long.



Figure 3. Wild buckwheat can be a problem in wheat. Note how the weed climbs the crop plant.



Figure 4. Note the narrow cotyledons and rounded base on this wild buckwheat seedling. The weed's leaves are alternate, heart- or arrowhead-shaped, and pointed at the tips.



Figure 5. Wild buckwheat produces flowers in short-stemmed clusters in the axils of the leaves or at the end of stems. Flowers are small and have no petals, but have five greenish or pinkish sepals.

Wild buckwheat is a member of the smartweed family. Like other smartweeds, wild buckwheat possesses an ocrea (thin membrane) around the stem at each node. It can be confused with field bindweed because of its vining growth habit and arrowhead-shaped leaves. Field bindweed, however, is a perennial, has an extensive underground root system, does not possess an ocrea, and has large funnel-shaped flowers that are white or pink. Also, wild buckwheat's lower leaves are usually much wider than bindweed leaves.

## Distribution and Emergence

Wild buckwheat is native to Europe and has become widely distributed in temperate regions via grain transport. Wild buckwheat also is one of the most common contaminants in all seed stock. Its seed is similar in diameter to wheat seed and is often planted with the grain (see Figure 6). At harvest, many seeds do not thresh completely from the seed coat and are especially difficult to clean from wheat. Wild buckwheat grows



Figure 6. Wild buckwheat seeds are one of the most common contaminants in all seed stock. This photo shows black, triangular wild buckwheat seeds mixed with wheat seeds. The two seeds are similar in diameter.

the growth of others. Applying the recommended glyphosate rate of 0.75 lb. ae/A (1 quart of 3 lbs. ae/gallon or 22 fl. oz. of 4.5 lbs. ae/gallon formulation) may result in poor control of small plants and will not control large wild buckwheat plants (Table 1). Wild buckwheat growing in adverse conditions makes control even more difficult.

Fortunately, resistant wild buckwheat biotypes have not been documented to any previously or currently used herbicide chemistries, including glyphosate.

**Table 1. Wild Buckwheat Control with Glyphosate Alone or Tank-mixed with Additional Herbicides**

Wild buckwheat height	glyphosate alone 0.75 lb. ae/A 0.3 oz./A	glyphosate @ 0.75 lb. ae/A +								glyphosate required for 90% control (lb. ae/A)
		Classic*	Flexstar*	Phoenix*	Raptor® 3	Scepter® 1.44 oz./A	Ultra Blazer® 2 fl. oz./A	Extreme® 48 fl. oz./A		
		Percentage of Wild Buckwheat Control								
3 inches tall	70	83	87	93	83	87	88	100	1	
6 inches tall, 12 inch runners	60	53	78	90	70	75	86	63	1.16	
6 inches tall, 24 inch runners	45	50	73	67	68	68	75	57	1.4	

Source: Steven Knezevic, University of Nebraska Haskell Agricultural Laboratory, Concord, Nebraska.

## Control

### Glyphosate

Wild buckwheat and related smartweed species have some natural tolerance to glyphosate. Wild buckwheat control from glyphosate is reduced when applications are made at lower than labeled rates, when only one glyphosate application is made, when plants are stressed from adverse environmental conditions, or when runners are more than 3 to 4 inches long. Glyphosate has no soil residual activity to control later weed flushes throughout the growing season.

### Other Effective Herbicides

The most effective herbicides on wild buckwheat are atrazine, bromoxynil, clopyralid, dicamba, glufosinate, and some sulfonylurea products. Using these herbicides or mixtures with these ingredients will ensure the most effective wild buckwheat control. Atrazine, clopyralid, dicamba, and some sulfonylurea herbicides may persist in the soil and carry over for more than one growing season, especially in soils with high pH. The long residual sulfonylurea herbicides effective on wild buckwheat are chlorsulfuron (Finesse®, Glean®) and triasulfuron (Amber®).

**Table 2. Wild Buckwheat Control**

Herbicide	Rate (product/A)	Small Grains	Corn	Soybeans
Aim*	0.5 fl. oz.	S	S	
Ally*	1/10 oz.	C		
Ally Extra*	2/10-4/10 oz.	C		
Amber*	0.28-0.56 oz.	C		
atrazine + premixes	0.38-0.5 lb. ai		C	
bromoxynil	1-2 pts.	C	C	
clopyralid (Stinger®)	0.25-0.67 pts.	C	C	
Callisto*	3/8-3/4 oz.	S/C		
Curtail*	2-2.67 pts.	C		
Curtail M*	1.75-2.33 pts.	C		
dicamba + premixes	2-4 fl. oz.	C	C	
Distinct*	4-6 oz.		C	
Extreme*	2.25-3 pts.			S/C
Finesse*	2/10-4/10 oz.	C		
Glean*	1/6-1/3 oz.	C		
glyphosate	0.75-1.75 lbs. ai	S/C	S/C	S/C
Harmony Extra*	3/10-6/10 oz.	S/C		
Harmony GT*	3/10-6/10 oz.	C		
Harmony GT®	1/12 oz.			S
Hornet® (PPI/PRE)	4-6 oz.		C	
Liberty* (Liberty Link®)	28-34 fl. oz.		C	
Lightning* (Clearfield®)	1.28 oz.		C	
Peak*	3 oz.		S	
Pursuit Plus*	1.8 pts.			C
Spartan*	3-8 fl. oz.			S
Valor*	2-3 oz.			S
Widematch*	1-1.33 pts.	C		

C = Control

S = Suppression

Empty boxes = not known

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# New or Unique Methods

- More emphasis on the value of soil-applied herbicides
  - Weed control variability
  - Late-season weed density and diversity
  - Yield variability
- Education on the concept of a low level of resistance
- Risk of various weed management practices for developing resistance
- N uptake by weeds
- Demonstrations
- Is repetition unique?

# Challenges and Future Educational Needs

- Cause of herbicide resistance and concept of low level of resistance
  - Convince some that it is an issue
  - “Not a problem unless it is in my field”
- Management tactics for specific troublesome weeds
- Provide economical means of implementing resistance mgt strategies
- Weed competition
- Proper rate, timing, and herbicide partner data and demonstrations
- Commodity group support and education

