Challenging Weed Species in Glyphosate-Resistant Crops

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The introduction and commercialization of glyphosate-resistant soybean varieties and corn hybrids has, in many ways, dramatically altered the weed management practices of farmers across much of the Midwest. Estimates place the adoption of herbicide-resistant soybean varieties and corn hybrids (principally glyphosate-resistant) at approximately 90 percent and 37 percent, respectively, of the U.S. soybean and corn acreage[1]. The adoption of this technology has, in many respects, simplified weed control for many farmers. For example, soybean farmers can use a single active ingredient (glyphosate) for postemergence control of many broadleaf and grass weed species. Application rates can be adjusted according to weed spectrum and size. No concerns exist for rotational crop injury from herbicide carryover. Simply stated, this new weed control "system" has worked well for many farmers.

But has this system perhaps work *too* well? Does this system simplify weed management decisions to the extent that *integrated* weed management consists only of one or more applications of glyphosate? Some might argue that "if the system ain't broke, don't fix it!" But if "problems" of one sort or another do develop that reduce the effectiveness of this system, what will soybean and corn farmers do then?

Weeds can adapt to particular management systems in a variety of ways. For instance, species that are not effectively controlled by a particular active ingredient may become increasingly prevalent following repeated use of that particular active ingredient (fall panicum became a problem weed in corn following the widespread adoption of atrazine). Another adaptation is that later-emerging weed species can become more prevalent in fields were soil-residual herbicides are not used or are used at reduced application rates. And, who can argue that selection for herbicide-resistant weed species continues to present new and significant challenges for corn and soybean farmers? The remainder of this proceedings paper will describe three weed species that can present challenges in glyphosate-resistant cropping systems.

Morningglories – weed species not particularly sensitive to glyphosate

Morningglory species, with their large, brightly colored flowers, are often favorites of many gardening enthusiasts. These plants grow well in a variety of soil types, produce a large amount of foliage during the hot and sunny days of summer, and aggressively cover trellises, poles, fences, etc. While a favored ornamental among many homeowners and gardeners, some morningglory species can be troublesome weeds in corn and soybean fields.

[1]United States Department of Agriculture National Agricultural Statistics Service June 2006 report.

Several species of annual morningglory occur in Midwest agronomic cropping systems, including tall (*Ipomoea purpurea*), ivyleaf (*I. hederacea*), and pitted (*I. lacunosa*) morningglory species. A perennial morningglory species (*I. pandurata*) that can be locally prevalent in Illinois and Indiana goes by several common names, including bigroot morningglory or wild sweet potato. Two other perennial species (field bindweed (*Convolvulus arvensis*) and hedge bindweed (*Calystegia sepium*)) also are members of the plant taxonomic family of the morningglories (Convolvulaceae), but do not belong to the genus *Ipomoea*. The family name Convolvulus is derived from the Latin verb meaning “to entwine”, while the genus *Ipomoea* comes from the Greek *ips* (“a worm”) and *homoios* (“resembling”), which refers to the wormlike twining as the plants grow around stationary objects.

Identification of the annual morningglory species can be accomplished as early as cotyledon-stage plants. Tall and ivyleaf morningglory seedling plants have butterfly-shaped cotyledons with rounded lobes, while the butterfly-shaped cotyledons of pitted morningglory are slender and more deeply notched with pointed lobes. The true leaves of tall morningglory are heart-shaped and covered with hairs that lie flat on the surface. True leaves of pitted morningglory are also heart-shaped but generally smaller than the leaves of tall morningglory with few to no hairs. The leaf margins are often tinged with a purple color and taper to a more pronounced pointed tip. Ivyleaf morningglory true leaves are very hairy and deeply 3-lobed.

Postemergence control of annual morningglory species in soybean can be challenging. These weed species can increase in size very quickly with adequate soil moisture and warm air temperatures, often exceeding labeled sizes in a short period of time. Emergence of annual morningglories occurs over a relatively long period of time compared with many other summer annual weed species, and is often enhanced following a precipitation event. Thus, achieving acceptable morningglory control in soybean with a single postemergence herbicide application can be difficult.

Postemergence herbicide options for morningglory control in soybean include both contact and translocated herbicides. Contact herbicide options include products containing the active ingredients fomesafen (Flexstar), lactofen (Cobra), and acifluorfen (Ultra Blazer). These products require thorough spray coverage of the target foliage to achieve optimal control, and work best when morningglory plants have not more than 4 true leaves. Translocated herbicide options for control or suppression of morningglory include glyphosate, cloransulam (FirstRate), imazamox (Raptor), and chlorimuron (Classic). Symptoms of herbicide injury on morningglory following the application of a translocated herbicide consist of an initial stunting and yellowing of the leaves. Injury symptoms are often slower to develop with translocated herbicides than with contact herbicides. 2,4-DB, at 1 to 2 fluid ounces per acre, is sometimes tankmixed with either contact or translocated herbicides to improve morningglory control but is rarely applied alone postemergence.

Soybean weed control practitioners are often frustrated when attempting to control morningglory postemergence exclusively with glyphosate. Glyphosate, at 0.75 to 0.77 lb ae per acre, is much more effective when morningglory are small (about 1 to 3 inches) than when applications are delayed until plants exceed 8 to 12 inches. If larger morningglory are present and the initial plan was to apply glyphosate at 0.75 to 0.77 lb ae, you may want to consider some alternatives that might improve overall morningglory control.

Three potential options for improved morningglory control include: (1) increasing the glyphosate application rate from 0.75 to 1.12 lb ae per acre, (2) sequential applications of glyphosate, spaced approximately 10 to 14 days apart, or (3) adding a tankmix partner to glyphosate. Field research conducted at the University of Illinois (as well as field research from several other universities) has demonstrated improved morningglory control from each of these options compared with a single application of 0.75 lb ae glyphosate. In some trials sequential glyphosate applications improved morningglory control more often than tankmixes, whereas in other trials tankmixes were equal to or better than sequential glyphosate applications. Overall, sequential applications or herbicide tankmixes are about “equal” with respect to the number of instances one tactic has improved control relative to the other.

Hophornbeam copperleaf (*Acalypha ostryifolia*) – a late-emerging annual weed species

Hophornbean copperleaf is a summer annual species in the Euphorbiaceae plant family. This plant family, also known as the Spurge family, includes several other problematic weed species, many of which have a milky sap. Hophornbeam copperleaf, however, does not contain the characteristic milky sap of other Euphorbiaceae family members. It is indigenous to Illinois, and most commonly found in the southern third of the state. Several other copperleaf species can be found in Illinois, and while most of these other species are not generally considered problematic in agronomic production systems, Virginia copperleaf (*Acalypha virginica*) can be a troublesome weed species in southern Illinois.

Hophornbeam copperleaf has pubescent cotyledons and true leaves with short hairs and finely toothed (serrated) margins. The leaves are simple and alternate and somewhat heart-shaped at the base. As plants become larger, a reddish coloration is often observed where the main leaf vein intersects the petiole. Hophornbeam copperleaf may sometimes be misidentified (especially during early vegetative development) as prickly sida (*Sida spinosa*), but certain morphological characteristics can be used to differentiate these two species. The leaf margins of prickly sida are more coarsely serrated than those of hophornbeam copperleaf, and hophornbeam copperleaf does not have the small stipules (spines) in the leaf axils like prickly sida.

Hophornbeam copperleaf is monoecious (both male and female flowers on the same plant), with staminate (male) flowers produced on axillary spikes and pistillate (female) flowers produced on a long, terminal spike. Seed capsules of hophornbeam copperleaf are three-lobed, dehiscent (capsules split open at maturity to release seed), and seeds appear to require warm temperatures for germination. A warm soil temperature germination requirement suggests this species is able to germinate and emerge later during the growing season. Emergence can begin in late May or early June, and may continue for most of the remaining growing season. Additional flushes of hophornbeam copperleaf frequently appear following precipitation. Recent experience has shown that hophornbeam copperleaf plants can be present during corn or soybean harvesting operations, and that many of the plants likely emerged after the crop reached full maturity. A recently published experiment reported the average seed production of hophornbeam copperleaf plants growing alone (without competition) was approximately 12,518 seeds per plant, much greater than the average seed production (980 seeds per plant) when grown with soybean. No data are available that describe seed longevity in the soil or potential seed dormancy.

Waterhemp – a species resistant to several herbicides (including glyphosate)

Although indigenous to Illinois, waterhemp was not considered much of a problem weed species in agronomic crops until it began to spread across the state sometime beginning about the late 1980s or early 1990s. Today, waterhemp populations continue to infest additional acres of farmland in central and northern Illinois, aided by several adaptations (some of which are unique to this weed species) that allow the species to thrive in contemporary agronomic crop production systems. Indeed, waterhemp has become perhaps the most recognized example of how a weed species is able to adapt to [[manmade?]]mad-made “environments”. One adaptation of particular importance that has allowed waterhemp to flourish is its ability to thwart attempts at control with herbicides.

The story of waterhemp management in agronomic crops has been anything but static, and even today the story continues to be written. No other weed species in Illinois has demonstrated more unique instances of herbicide resistance than has waterhemp. In 1994, Dr. Loyd Wax alluded to the forthcoming possibility of selecting waterhemp biotypes resistant to ALS-inhibiting herbicides. By 2002, we had reported how pervasive herbicide resistance in waterhemp actually had become across Illinois. Over a two-year period, approximately 60 waterhemp collections from 30 Illinois counties were made to examine the extent of herbicide resistance in the Illinois waterhemp population. Female waterhemp plants were randomly selected from corn and soybean fields (no knowledge of herbicide use history for any field sampled), seedling plants grown in the greenhouse, and treated with a triazine herbicide (atrazine) or an imidazolinone herbicide (imazethapyr).

Greenhouse results indicated approximately 25 percent of the samples produced progeny resistant to atrazine, while approximately 90 percent of the populations demonstrated resistance to ALS-inhibiting herbicides. Within the atrazine-resistant populations, there appeared to be at least two different mechanisms of resistance, along with variation in patterns of cross-resistance to other triazine herbicides and inheritance of the resistance trait(s). Similarly, within the ALS-inhibitor resistant populations, there were different mechanisms of resistance that affected patterns of cross-resistance to the various ALS-inhibiting herbicides. Intermingled with the herbicide-resistance screening research, Illinois weed scientists also reported the confirmation of a waterhemp biotype from Bond County, Illinois that was resistant to both ALS-inhibiting herbicides and triazine herbicides. This marked the inaugural report of multiple herbicide resistance in waterhemp, but the story would continue to evolve.

Weed control practitioners know there are only four active ingredients for postemergence waterhemp control in soybean, and three of these belong to one chemical family. The diphenylether herbicides (PPO-inhibitors) acifluorfen (Ultra Blazer), fomesafen (Flexstar), and lactofen (Cobra/Phoenix) were once used extensively for waterhemp control in soybean, until being largely displaced by glyphosate. These products were often applied alone to control waterhemp, but frequently they were used as tankmix partners with one or more of the postemergence ALS-inhibiting broadleaf herbicides. For many years, diphenylether herbicides were the primary weapons against waterhemp in soybean, and we learned that the most consistent control of waterhemp with these herbicides was achieved when applications were made to plants less than 6 inches in height. However, during the 2001 growing season, several reports from around Illinois indicated that waterhemp control was much less than expected following applications of diphenylether herbicides. We began investigating a population of waterhemp from western Illinois that was not controlled by postemergence applications of diphenylether herbicides during the 2001 growing season, nor with lactofen (Cobra at 20 fluid ounces plus crop oil concentrate) under greenhouse conditions. Given these observations from the field and our results from greenhouse research, we began experiments to determine how this waterhemp population responded to various soil-applied and postemergence herbicides under actual field conditions.

It soon became obvious that this waterhemp biotype did in fact demonstrate resistance to various PPO-inhibiting herbicides. After several years of extensive field, greenhouse, and laboratory research, in 2005 we reported the confirmation that this waterhemp biotype was resistant to not simply one herbicide family, but three herbicide families: ALS inhibitors, PPO inhibitors, and triazines. This marked the first-ever report of three-way herbicide resistance in a summer annual weed species in the United States. Additionally, we recently published the results of research that identified a unique mechanism of resistance that this waterhemp biotype uses to survive exposure to PPO herbicides. And so, the story of waterhemp management in agronomic crops continues to evolve.

The fourth postemergence herbicide option for waterhemp control in soybean is glyphosate. Glyphosate has been a very effective herbicide against waterhemp since its in-crop utilization rapidly escalated following the commercialization and adoption of glyphosate-resistant soybean varieties. Many soybean farmers have come to rely exclusively or near exclusively on glyphosate for waterhemp control in lieu of a more integrated waterhemp management approach. For many years, glyphosate seemed to be the remedy for all the problems and challenges presented by waterhemp. However, during the past several growing seasons we have received an increasing number of reports of glyphosate failing to provide adequate control of waterhemp (and a few other weed species). Other states have reported similar observations. While perhaps not always meeting the criteria for being designated "resistant" to glyphosate, lack of control for whatever reason presents a problem. The story, however, continues to unfold.

The moniker, "glyphosate-resistant," now has been attached to waterhemp populations from Missouri, Illinois, Kansas, and Texas. Weed scientists at the University of Illinois have conducted field, greenhouse, and laboratory research with an Illinois waterhemp population that is not controlled at field use rates of glyphosate-containing products. While evidence to date suggests this *particular* population is in fact resistant to glyphosate, it is altogether likely that other populations of glyphosate-resistant waterhemp exist across the state. Indeed, anecdotal reports in 2007 suggested glyphosate-resistant waterhemp may be present in several fields, ranging from counties in southeast Illinois to west-central Illinois. Observations suggested putative glyphosate-resistant waterhemp populations were more prevalent in soybean than corn, but there is scant reason to believe these biotypes were not present in the 2007 Illinois corn crop.

Managing glyphosate-resistant waterhemp is a significant consideration regardless of the crop (corn or soybean) these populations infest. If the herbicide-resistance profile of a particular waterhemp population is known, appropriate changes in herbicide selection and utilization (particularly postemergence soybean herbicides) can be made well before the 2008 growing season. However, apart from the general assumption that most Illinois waterhemp populations are resistant to ALS-inhibiting herbicides, the vast majority of populations remain uncharacterized with respect to their susceptibility to the limited number of postemergence soybean herbicides available for waterhemp control.

Will the incidence of glyphosate-resistant waterhemp be sufficient to persuade changes to weed management programs, especially in soybean production? Only time will provide an accurate answer. However, weed scientists continue to stress several points related to glyphosate-resistant weeds and glyphosate stewardship:

1. A selection pressure for herbicide-resistant weeds occurs each time the same herbicide is applied to a particular field.
2. Increased adoption of glyphosate-resistant corn hybrids, with a concomitant use of glyphosate to the exclusion of other weed management tools, will speed the selection of glyphosate-resistant weeds.
3. Rotating herbicides (sites of action) or tankmixing herbicides will help slow the selection of glyphosate-resistant weeds but is unlikely to completely prevent their selection. Keep in mind that it's nearly impossible to make "blanket statements" about how effective a particular alternative herbicide or tankmix partner will be in slowing the selection of glyphosate-resistant weeds.
4. Stewardship of glyphosate herbicide is an easy concept to discuss but more difficult to implement.

This historical perspective of waterhemp's notorious expansion across Illinois has been given to illustrate an important point. Waterhemp is a very diverse plant species, as is evidenced by the selection of biotypes resistant to ALS-inhibitors, triazine herbicides, PPO-inhibitors, and glyphosate. It's become somewhat "old news" that much of the

Illinois waterhemp population is resistant to ALS-inhibiting herbicides or that many populations are resistant to triazine herbicides. Resistance to PPO-inhibiting herbicides is perhaps more widespread in Illinois than many people assume, but the near-ubiquitous utilization of glyphosate on Illinois soybean acres has likely masked the full extent of PPO-resistant waterhemp. The preponderance of evidence suggests it is only a matter of time until glyphosate-resistant weeds (waterhemp, in particular) begin to occupy places in the Illinois agronomic landscape.

In years past, many new herbicide active ingredients were commercialized for the soybean market, but that has changed. It is unlikely that many (if indeed any) new active ingredients with good postemergence efficacy on waterhemp will be introduced into the soybean market during the next few years. If the effectiveness of currently available postemergence soybean herbicides for waterhemp control continues to be reduced, waterhemp management may reach a new level of difficulty, as there may not be any new solutions that come to market, at least for the foreseeable future.

One way to reduce the selection of herbicide-resistant waterhemp biotypes is to integrate multiple control tactics, such as utilization of soil-applied and postemergence herbicides, mechanical cultivation, or all three. Research conducted by weed scientists at several universities during the 1990s indicated that many soil-applied corn and soybean herbicides demonstrate good waterhemp control, but few consistently provide season-long waterhemp control. Our recommendation has been, and will continue to be, that the most consistent programs for waterhemp management include soil-applied and postemergence herbicides, along with mechanical cultivation where feasible. Experience has shown that continued heavy reliance on a single herbicide active ingredient, to the exclusion of other management tactics, ultimately speeds the selection of herbicide-resistant weeds. Glyphosate will not be an exception.

Sources:

Defelice, M. S. 2001. Tall morningglory, *Ipomoea purpurea* (L.) Roth - flower or foe? Weed Technology 15:601-606.