Managing Herbicide Resistance in Cotton Cropping Systems

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Summary

Resistance occurs when a genetic change allows a population of weeds to survive a herbicide treatment to which the original population was susceptible. Individual plants of weed species that are resistant to a particular herbicide are typically present in untreated populations at very low frequencies. These few resistant individuals survive a herbicide application and reproduce, whereas susceptible individuals are killed and do not reproduce. The percentage of resistant individuals increases over time as the herbicide treatment is repeated. Weed scientists began identifying resistant weed biotypes (genotypes) about 40 years ago, and the number of weeds with resistant biotypes has increased in recent years. Use of a few modes of herbicide action in the major row crops, cotton (*Gossypium hirsutum*), corn (*Zea mays*), and soybean (*Glycine max*), has selected for resistance in certain weeds. Widespread use of the acetolactate synthase (ALS) inhibiting herbicides and glyphosate has led to resistance to one or both of these modes of action in weeds including Palmer amaranth (*Amaranthus palmeri*), common cocklebur (*Xanthium strumarium*), and horseweed (*Conyza canadensis*). Growers should diversify weed management tactics to avoid selecting more resistant weeds. Scout to detect uncontrolled weeds early and prevent movement of possibly resistant weed seed among fields. To reduce the rate of resistance buildup, practice rotation of all management factors where possible, including type of tillage, crops grown, and herbicide modes of action. Crop monoculture and continuous use of the same modes of action will accelerate resistance buildup and increase the difficulty and cost of weed control.

What is Herbicide Resistance?

Herbicide resistance is the inherited ability of a weed biotype to survive and reproduce despite exposure to a dose of herbicide that previously was effective on an unselected population. Application of a herbicide may reveal individuals within a population that already possess the capacity to survive exposure. Repeated, successive use of one herbicide, or herbicides with the same mode of action, increases the likelihood that resistant individuals will survive and reproduce.

How are Weed Populations Selected for Resistance?

The rate at which a resistant weed population is selected depends on the number and frequency of herbicide applications the population receives, the size of the population and its genetic diversity, and characteristics of the herbicide target site. Resistance buildup is accelerated when the management of crops does not include diverse tactics that limit herbicide use such as crop rotation and mechanical weed management. For example, there may be more opportunities for resistance buildup in conservation tillage because weeds are not killed by mechanical disturbance and non-selective herbicides such as glyphosate, paraquat, or glufosinate are used for pre-plant burndown.

What are Herbicide Modes of Action?

Mode of action describes the plant process affected by the herbicide that results in death of susceptible plants. The mode of action involves the physiology of the weed and typically involves interference with a specific biochemical mechanism that the weed requires for growth and development. Herbicides with similar chemical structures tend to have the same mode of action. The herbicides labeled in all major row crops represent only a few modes of action. (Table 1.) See the training module – http://www.cotton.org/tech/pest/wrm.

Table 1. Modes of Action of Herbicides Widely Used in Cotton, Soybean, and Corn.

WSSA Code[1]	Herbicide Mode of Action	Representative Products[2]
1	ACCase Inhibitors	Assure, Fusilade, Poast, Select, Whip
2	Acetolactate Synthase (ALS) Inhibitors	Accent, Broadstrike, Cadre, Classic, Envoke, Finesse, Glean, Harmony Extra, Osprey, Pursuit, Raptor, Resolve, Scepter, Staple, Strongarm, Stout
15	Very Long Chain Fatty Acid Synthesis Inhibitors	Dual, Harness, Outlook, Intrro
3	Microtubule Assembly Inhibitors	(DNA Herbicides) Prowl, Sonalan,Treflan
9	EPSP Synthase Inhibitors	(Glyphosate) Glyphomax, Roundup, Touchdown
10	Glutamine Synthase Inhibitors	(Glufosinate) Ignite, Liberty
5	Photosystem II Inhibitors	AAtrex, Caparol, Cotoran, Direx, Linex, Layby Pro, Lexone/Sencor
14	Protoporphyrin Oxidase Inhibitors	Aim, Blazer, Cobra, ET, Flexstar, Goal, Reflex, Resource, Valor

[1] Weed Science Society of America Mode of Action Codes
[2] Registered Trademarks

A Weed Control Failure is Usually Not Resistance

In most cases, weed control failures that follow herbicide treatments are not due to herbicide-resistant weed populations. Herbicide failure can be caused by factors such as the following: 1) herbicide misapplication such as poor spray coverage, applying less than the label-recommended rate, or treating when weeds are too large; 2) adverse environmental conditions due to heat or cold, drought or excessive moisture, or insect or mechanical damage; 3) wash-off of postemergence applications; 4) excessively high weed populations; and 5) new emergence following treatment.

Suspect resistant weeds? You may be correct if –

- √ The field has been sprayed repeatedly with the same herbicide (or the same mode of action) and
- √ A patch of weeds occurs in the same spot year after year and is spreading,
- √ Many weed species are controlled, but one particular species is no longer controlled, and
- √ Surviving weeds of the problem species may be in a patch where some are dead, and some show variable symptoms, but all are approximately the same age as those that were treated and controlled.

Status of Weed Resistance to Herbicides

The occurrence of herbicide-resistant weeds worldwide is tracked on the website: http://www.weedscience.org. The site is sponsored by the Herbicide Resistance Action Committee (HRAC), an organization comprised of several pesticide manufacturers and by the Weed Science Society of America. In 2006, over 300 cases of resistance were listed. Very few cases were reported until the late 1970s. During the early 1980s, most reported resistance was to Photosystem II inhibitors, such as atrazine. After the ALS inhibiting herbicides were introduced in the mid-1980s, there was a sharp increase in reported incidences. Glyphosate resistance was first reported in rigid ryegrass (*Lolium rigidum*) in Australia in 1998. Glyphosate-resistant horseweed was identified in the U.S. in 2000, and is now a widespread problem in cotton and soybean production. In 2005, glyphosate-resistant Palmer amaranth was discovered in Georgia. There are now eleven weeds with confirmed glyphosate-resistant biotypes worldwide. Additionally, weeds have the ability to possess multiple resistance mechanisms, whereby a biotype is resistant to more than one mode of action.

Table 2. Troublesome Weeds with Populations Resistant to Certain Herbicide Modes of Action.

Weed Species	ACCase[1]	ALS	DNA	Glyphosate
Palmer amaranth	No	**Yes**	**Yes**	**Yes**
Common cocklebur	No	**Yes**	No	No
Common ragweed	No	**Yes**	No	**Yes**
Horseweed	No	**Yes**	No	**Yes**
Goosegrass	Yes[2]	No	**Yes**	Yes[2]
Johnsongrass	**Yes**	No	No	Yes[2]
Ryegrasses	**Yes**	**Yes**	No	**Yes**

[1] Resistance to the indicated Mode of Action. See Table 1.
[2] Resistant biotypes of these weeds not found in the U.S.

General Principles for Delaying Resistance

- √ Diversify crop production practices. Rotate crops, tillage practices, and herbicide modes of action when possible. Using different approaches helps reduce the likelihood of buildup of any particular weed species and other pests.
- √ Use rates of herbicides that are recommended for the size of the weeds treated. Use of recommended rates minimizes the survival of less susceptible weeds.
- √ As much as possible, include herbicides with different modes of action in the weed management program for each crop grown on the same ground. Rotation of herbicides with different modes of action among years is the most efficient resistance management practice. Using multiple modes of action within each year tends to minimize survivors, and will also help to slow reproduction of resistant populations.

√ **For cotton, specific measures include:**
- Use preemergence and postemergence herbicides with different modes of action.
- Tank-mix postemergence herbicides with different modes of action.
- Use different herbicide modes of action at layby than those used in preceding treatments.

√ Limit the soil seed bank by continuously maintaining high levels of weed control.

√ Survey the weed population each season and record observations. Scout for weeds that escaped treatment and apply spot treatments or cultivation where appropriate and practicable, or other applicable approaches, including hand removal, to prevent weed seed production.

√ Keep a record of herbicide applications.

√ If resistant populations are present, clean equipment and vehicles before moving to fields where resistant populations have not been found. Likewise prevent movement of soil and plant debris from infested fields to clean fields.

√ Look for areas of fields where one species of weed appears to survive control.

√ If a weed control failure has occurred, kill the surviving weeds by means other than reuse of the failed treatment. Do not repeat the failed practice next season.

A Recipe for Resistant Weeds: Use a Single Herbicide

Cotton was planted on over 14 million acres in 2005. Over 80% of these acres were planted with Roundup Ready® (glyphosate-resistant) varieties. Crops that may be rotated with cotton include soybean, corn, wheat (*Triticum aestivum*) or grain sorghum (*Sorghum bicolor*); however, from 1996 to 2000, the vast majority of cotton (74%) was grown as a continuous monoculture. Texas, Georgia, Mississippi, Arkansas, and North Carolina represent over 10 million acres of cotton. All of these states except Texas planted 97 to 99% glyphosate-resistant varieties in 2006. Although different herbicides may be used in corn and soybean than in cotton, Roundup Ready cotton rotated with Roundup Ready soybean still represents a regime of continuous glyphosate treatment. Increased adoption of Roundup Ready corn also will likely increase the acres where glyphosate is used continuously.

The Cotton Belt has become dependent on glyphosate-based crop production systems. With such dependence has come concern for development and spread of glyphosate-resistant weeds.

Practicing Resistance Management

Tillage: Although the reduced costs associated with conservation tillage are a major advantage, mechanical weed control may be very helpful when difficult-to-control weeds are found.

Crops and Varieties: Rotate crops if possible. Rotate conventional, Roundup Ready and Liberty Link cotton varieties when possible.

Herbicides: In this document, we use examples of herbicide programs for management of weeds resistant to glyphosate and ALS inhibitor herbicides. Some recommended herbicide programs for managing resistance to glyphosate and ALS inhibitors in corn, soybean, and cotton are presented in Tables 3 to 5. All herbicides should be applied broadcast, unless the crop is concurrently cultivated. **Each state has weed control recommendations for various crops with additional details.**

Using Tables 3-5: **Use herbicides at full rates sufficient to control target species and not later than timings specified on labels.** Within technologies and resistance situations, choose herbicides for each stage of application that will control the weeds that will be present. To the extent possible, choose herbicides with different modes of action at each stage. A rule of thumb to slow resistance is to include residual herbicides, with different modes of action, into the program starting from preplant burndown through layby.

Glyphosate- and ALS-resistant Palmer amaranth are serious concerns. An aggressive management program is necessary to slow the spread of resistance and to reduce selection in areas not infested with resistant biotypes. Be vigilant about uncontrolled patches of weeds. Weeds in patches that resist control should be investigated. If a weed management program has failed, do not repeat it in the same field. Many outright control failures due to resistant weeds have been discovered from the repeat application of previously failed treatments, with disastrous economic results.

Table 3. Herbicide Programs for Managing Glyphosate- and ALS-Resistant Pigweeds in Field Corn.

Corn Hybrid	Preemergence	Postemergence	Layby as needed
Non-Transgenic		Prowl + Atrazine + Crop Oil or Callisto, Lumax, or Lexar	2,4-D[1], Evik, or Lorox, as needed
Non-Transgenic	Atrazine, Bicep II Magnum, Bullet, Guardsman Max, Lariat, Lexar, or Lumax	Banvel[1], Clarity[1], Distinct[1], or 2,4-D, as needed	Same as Above
Liberty Link	Atrazine, Dual II Magnum, Micro-Tech, Lexar, Lumax, or Outlook	Liberty + Atrazine or Callisto, Lexar, or Lumax	Same as Above
Roundup Ready	Atrazine, Bicep II Magnum, Bullet, Guardsman Max, Lariat, Lumax, or Lexar at 66% normal rate	Glyphosate + Atrazine or Expert or Callisto	Same as Above

[1] Follow all label instructions to avoid drift to sensitive crops, such as cotton, tobacco, soybean, and vegetables. Use amine formulations of 2,4-D.

Table 4. Herbicide Programs for Managing Glyphosate- and ALS-Resistant Pigweeds in Soybeans.

Soybean Variety	Preemergence	First Postemergence	Second Postemergence
Roundup Ready	Dual Magnum, Intrro, Outlook, Prefix, Prowl, Canopy, Sencor, or Valor[1]; or Dual Magnum or Outlook + Canopy or Sencor	Glyphosate + Flexstar[1] or Glyphosate + Ultra Blazer[1] or Glyphosate + Storm[1] or Glyphosate + Cobra[1]	If needed, use a different herbicide than previously. Flexstar, Ultra Blazer, Storm, or Cobra
Non-Transgenic	Canopy or Sencor + Dual Magnum, Intrro, Outlook or Prowl	Flexstar or Ultra Blazer or Storm or Cobra	Same as Above
Non-Transgenic	Prefix or Prowl + Valor[1]	Same as Above	Same as Above

[1] Valor, Cobra, Reflex, and Ultra Blazer have the same mode of action. Use no more than two applications of these herbicides per season.

Table 5. Weed Control Programs for Managing Glyphosate- and ALS-Resistant Weeds in Cotton. [1,2]

Cotton Variety	Glyphosate Resistance Suspected	ALS Resistance Suspected	Preplant Incorporated or Preemergence	Postemergence 1- to 4-leaf cotton	Layby Options (Palmer < 3 in.)
Any	Yes or No	Yes or No	----------**Burndown Options**---------- Glyphosate + Clarity, 2,4-D, Express, Harmony Extra, Prowl or Valor; Ignite + 2,4-D or Clarity; Gramoxone + Direx or Caparol		
Roundup Ready	No	Yes	Prowl or Treflan PPI or Prowl, Cotoran, or Reflex PRE or Prowl + Cotoran	Glyphosate or Glyphosate + Dual Magnum (or Sequence)	MSMA or Glyphosate + Caparol, Direx, Suprend, or Valor or Layby Pro or Layby Pro + MSMA
Roundup Ready	Yes	No	Prowl or Treflan PPI followed by Cotoran, Reflex or Staple PRE or Prowl + Reflex or + Staple[3] PRE	No Palmer emerged: Glyphosate + Dual Magnum (or Sequence) as needed	MSMA + Caparol, Direx, Suprend, or Valor or Layby Pro or Layby Pro + MSMA
				Palmer < 2 in.: Glyphosate + Staple	Same as Above
Liberty Link	Yes or No	No	Prowl or Treflan PPI followed by Cotoran, Reflex or Staple PRE or Prowl + Cotoran, Staple or Reflex PRE	Palmer < 2 in.: Ignite + Dual Magnum as needed	Same as Above
				Palmer > 2 in.: Ignite + Staple	Same as Above
Liberty Link	Yes or No	Yes	Prowl or Treflan PPI followed by Cotoran or Reflex PRE or Prowl + Cotoran or Reflex PRE	Palmer < 2 in.: Ignite + Dual Magnum as needed * Palmer must be less than < 2 in. for acceptable control	MSMA + Caparol MSMA + Direx MSMA + Layby Pro MSMA + Valor
Non-Transgenic	Yes or No	Yes	Same as Above	MSMA + Cotoran, or Caparol, only as a directed application	Same as Above

[1] For Glyphosate-resistant Palmer amaranth, hooded sprays with paraquat mixtures, cultivation, and/or hand weeding will often be required.
[2] Herbicide labels vary among regions. Follow labels for soils and regions. Note that in Texas west of I-35, Reflex cannot be used preemergence, and Suprend cannot be used postemergence – directed.
[3] Limit Staple use to once per season.

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