SS-AGR-243

UF UNIVERSITY of FLORIDA
IFAS Extension

Herbicide Resistant Weeds[1]

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Herbicides work by disrupting biological pathways that allow plants to produce sugars and others compounds that are needed for growth. The location where a herbicide interrupts a pathway is called the **site of action.** For instance, the site of action for atrazine is photosystem II of the photosynthetic pathway. In some cases, different herbicides have the same by site of action (e.g. 2,4-D and Banvel (dicamba) are both synthetic auxins that interfere with natural plant auxin). The Weed Science Society of America developed a classification system to group herbicides by their site of action. Grouping herbicides by site of action provides a simple tool for determining which herbicides kill plants in the same way. Table 1 lists the herbicide groups and herbicides that are registered for use in Florida.

Herbicide performance is a complex issue that is influenced by many factors. These include spray coverage, application method, herbicide rate, environmental conditions, and weed size, to name a few. Poor or incomplete control may also be due to the ability of a weed to tolerate a particular herbicide. **Herbicide tolerance** is the inherent ability of a species to survive following a herbicide treatment. There was no selection to make the plant tolerant; it simply possesses a natural tolerance. For instance, most grass species are tolerant to 2,4-D. **Herbicide resistance** is different from tolerance and is defined as the *inherited* ability of a plant to survive a herbicide application to which the natural or wild-type is susceptible. For example, goosegrass is normally susceptible to paraquat, but some populations contain plants that have undergone a genetic change that makes them less susceptible. When these populations are treated with paraquat, the normal biotypes are controlled, while the resistant biotypes survive.

Extremely small numbers of herbicide-resistant individuals naturally occur in plant populations. There is no evidence that herbicides cause the genetic changes that result in herbicide resistance. Herbicides simply select for herbicide-resistant individuals that already occur in the population by controlling susceptible plants and allowing the resistant plants to survive and reproduce. Eventually, all that is left are the resistant plants, and the herbicide is no longer

1. This document is SS-AGR-243, one of a series of the Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date December 2005. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.

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effective. See Figure 1 for an example. Once selected for, resistant plants can remain in the population for many years.

In addition to being resistant to a single herbicide, some resistant plants can be classified as having **cross resistance** or **multiple resistance.** Cross resistant plants have resistance to two or more herbicides from the same group (same site of action). For example, if you have a population of pigweed that has developed resistance to atrazine, a Group 5 herbicide, it is likely that these pigweed plants will also be resistant to the Group 5 herbicides simazine and metribuzin (Sencor). Although it is much less common, weeds can also have multiple resistance. Multiple resistant weeds are resistant to two or more herbicides with different sites of action. For example, in Indiana a biotype of horseweed/marestail is resistant to glyphosate (Group 9), 2,4-D (Group 4), and chloransulam (Group 2) (Creech et al. 2004, NCWSS 2004 Proceedings).

The first recorded herbicide-resistant weed, 2,4-D resistant spreading dayflower (*Commelina diffusa*), was identified in 1957 in a sugarcane field in Hawaii. Today an estimated 300 weed biotypes are resistant to one or more herbicides worldwide (Figure 2). Currently in Florida, only 4 resistant biotypes (American black nightshade, goosegrass, hydrilla, and dotted duckweed) have been documented. However, it is likely that other undocumented herbicide resistant weed populations occur throughout the state. Continually updated information on the status of herbicide-resistant weeds can be found at http://WeedScience.org/in.asp.

Detecting Herbicide Resistant Weed Populations

Because weed control is rarely 100% effective, herbicide resistant populations often go undetected until they represent about 30% of the population. As the ratio of resistant to susceptible weeds increases, irregular patches of a single weed species will begin to appear. The patches may be reason to suspect herbicide resistance if:

1. Application problems can be ruled out.
2. Other weed species are controlled adequately.
3. The suspected weed species doesn't show symptoms of herbicide treatment and is growing in close proximity to dying plants of the same species.
4. There has been a previous failure to control the same species in the same field with the same herbicide or a herbicide from the same group.
5. Records show repeated use of one herbicide or one group of herbicides.

Preventing Herbicide Resistant Weeds

The appearance of herbicide-resistant weeds is usually linked to repeated use of the same herbicide or several herbicides from the same group (same site of action). For example, continuously applying only glyphosate for weed control in Roundup Ready cotton has resulted in the selection of glyphosate (Group 9) resistant Palmer amaranth. Weed management programs that use herbicides from different groups will delay or prevent the selection of herbicide resistant weed populations. When developing a herbicide rotation plan, it is critical make sure that the herbicides you wish to use are in different groups. For instance, you might consider rotating the herbicides Assure II, Select, and Beacon for johnsongrass control; however, if you referred to Table 1 you would find that Assure II and Select are both Group 1 herbicides. A more ideal herbicide rotation for johnsongrass control might include Assure II or Select (Group 1), Beacon (Group 2), and glyphosate (Group 9).

When it allows for increased herbicide flexibility, crop rotation can be an effective resistance management strategy. However some herbicides or herbicide groups are used in many different crops. For example, Group 2 herbicides are labeled for use in pastures, wheat, barley, corn, soybeans, cotton, peanuts, rice, vegetables, and other crops. Consequently, crop rotation does not automatically result in herbicide rotation. When planning a herbicide program, refer to Table 1 to verify that the herbicides you are using are in different groups.

Tank mixes generally are not an effective resistance management strategy and should only be used when the herbicide combination is needed to control the weed spectrum or herbicide rates can be reduced. Tank mixing for other reasons is not economically or ecologically sound.

Cultivation and spot spraying can be used to remove weed escapes that may be a result of herbicide resistance. Assuming that herbicide resistant and non-resistant plants germinate at the same time, tillage can control both equally well. In chemical fallow situations, use a herbicide from a different group than the herbicide used for weed control in the crop.

Accurate record-keeping is essential to effectively manage the development of herbicide-resistant weed populations. In order to have an effective herbicide rotation or tank-mix system to prevent resistance, you must know which herbicides have been used in the past, at what rate, and how often.

The use of an integrated weed management program that incorporates all the tools available to control weeds, including cultural, mechanical, and chemical methods, will slow or prevent the development of herbicide resistant weed populations.

For detailed information on properly managing herbicides for the preventing herbicide resistant weeds in specific cropping systems or pastures refer to: UF/IFAS publication SS-AGR- *Managing Against the Development of Herbicide Resistant Weeds: Sugarcane*; others to follow.

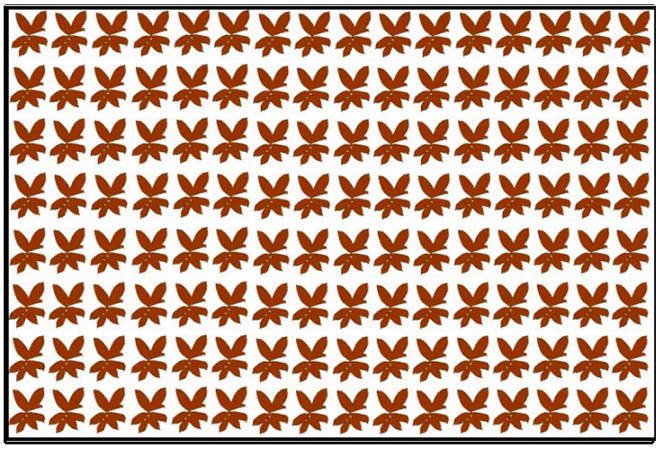

Figure 1.a

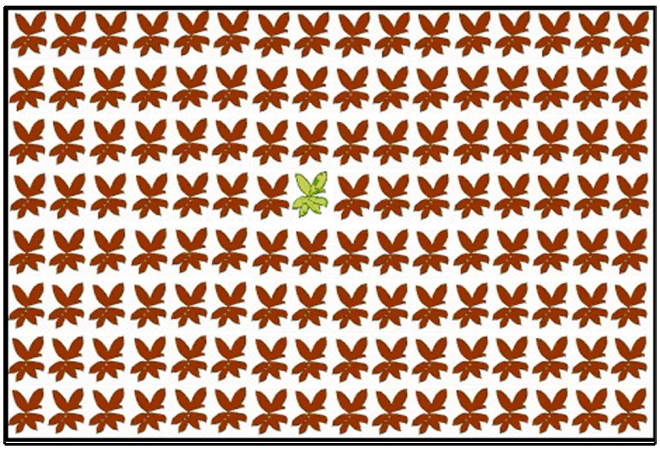

Figure 1.b

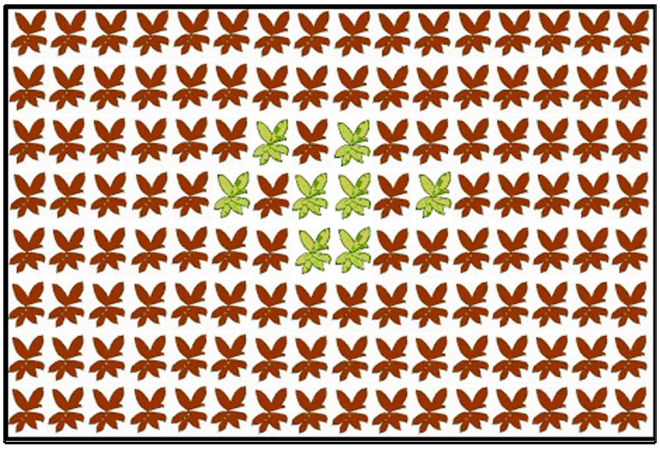

Figure 1.c

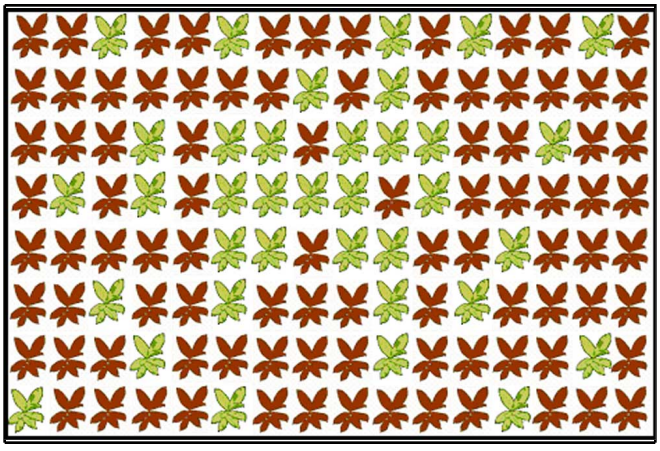

Figure 1.d

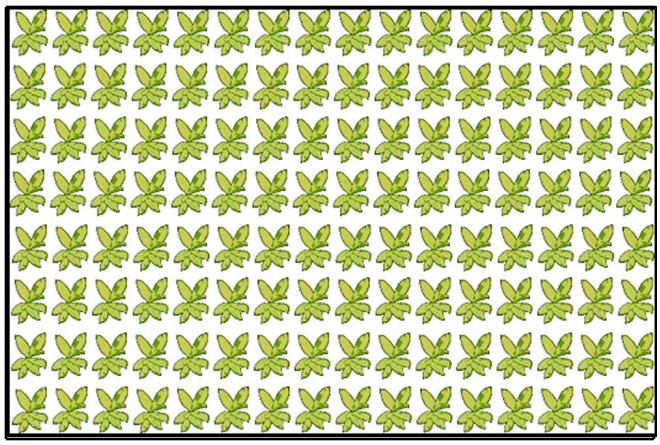

Figure 1.e

Figure 1. A possible progression of selection for resistant weed biotypes when a single herbicide or site of action is used continuously or without adding a herbicide with a different site of action to the tankmixture. Initially, good control would be observed providing application factors were optimal for herbicide activity (A). After several applications, a single plant may survive, grow and reproduce seed (B). That seed would germinate the following year and as a result, more plants would not be controlled the following year (C). As selection pressure continues, one would begin noticing a reduction in herbicide performance when the resistant population in the field approaches approximately 30% of the weed population (D). Providing the same selection pressure is applied to the field, the resistant weed population will continue to increase until nearly 100% of the population is resistant (E).

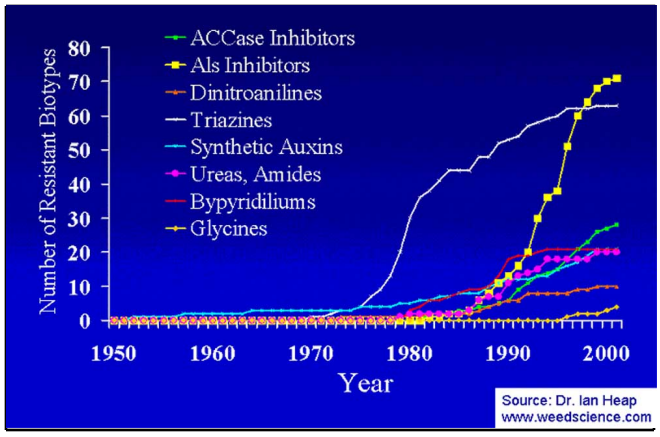

Figure 2. World-wide occurrence of herbicide-resistant weed biotypes. Addition of all biotypes resistant to each of the sites of action totals to greater than 300 different biotypes as of 2000.

Table 1. Group number and site of action of herbicides registered for use in Florida (compiled Fall 2005).

Group number and site of action	Chemical Family	Common Name	Trade Name(s)
Group 1 Acetyl CoA carboxylase (ACCase) inhibitors	aryloxyphenoxy-propanoates	cyhalofop	Clincher
		diclofop	Illoxan
		fenoxaprop	Acclaim Extra, Fusion[1]
		fluazifop	Fusilade, Fusion[1], Ornamec
		quizalofop	Assure II
	cyclohexanediones	clethodim	Envoy, Select, Volunteer
		sethoxydim	Poast, Poast Plus
		tralkoxydim	Achieve
Group 2 Acetolactate synthase (ALS) inhibitors	benzoate	pyrithiobac	Staple
	imidazolinones	imazapic	Cadre
		imazapyr	Arsenal, Lightning[2], Stalker
		imazamox	Raptor
		imazaquin	Scepter
		imazethapyr	Lightning[2], Pursuit, Pursuit Plus[3]
	pyrimidunyloxybenzoic	bispyribac-sodium	Regiment, Velocity
	sulfonylureas	bensulfuron	Duet[4], Londax
		chlorsulfuron	Corsair, Landmark[5], Telar
		halosulfuron	Permit, Sempra, Sandea, Sedgehammer, Yukon[5]
		nicosulfuron	Accent
		trifloxysulfuron	Envoke
		chlorimuron	Synchrony[7]
		metsulfuron	Ally, Escort, Oust Extra[8]
		tribenuron	Express, Harmony Extra[9]
		sulfometuron	Landmark[5], Oust, Oust Extra[8], Oustar[10], Westar[10]
		sulfosulfuron	Outrider
		thifensulfuron	Harmony GT, Harmony Extra[9] ,Synchrony[7]
		rimsulfuron	Matrix, Tranxit
	triazolopyrimidine	cloransulam	Firstrate, Frontrow
		flumetsulam	Frontrow

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Group 3 Microtubule assembly inhibitors	dinitroanilines	ethalfluralin	Curbit, Sonalan
		oryzalin	Oryza, Oryzalin, Snapshot, Surflan
		pendimethalin	Prowl, Pursuit Plus3, others
		prodiamine	Barricade, Endurance
		trifluralin	Treflan, Trifluralin
	no family name	DCPA	Dacthal, Dagger
	pyridine	thiazopyr	Mandate
Group 4 Synthetic auxins	phenoxy acetic acids	2,4-D	many, Outlaw11, Trimec11
		2,4-DB	many
		MCPA	Power Zone19
		MCPP (mecoprop)	Outlaw11, Trimec11, Power Zone19
	benzoic acid	dicamba	Banvel, Distinct, Outlaw[11], Trimec[11], Yukon[5], Power Zone[19]
	carboxylic acids	clopyralid	Confront[12], Lontrel, Redeem[12], Transline
		fluroxypyr	Pasturegard[13], Spotlight
		triclopyr	Confront[12], Garlon, Grandstand, Pasturegard[13], Pathfinder, Redeem[12], Remedy
	quinoline carboxylic acids	quinclorac	Drive
Group 5 Photosystem II inhibitors	triazines	ametryn	Evik
		atrazine	Aatrex, Atrazine, Bicep II Magnum[14], Lexar[15]
		hexazinone	K4[16], Oustar[10], Velpar, Westar[10]
		metribuzin	Sencor, Lexone, Metribuzin
		prometryn	Caparol, Cotton Pro, Prometryn, others
		simazine	Princep, Simazine
	phenylcarbamate	phenmedipham	Spin-Aid
	uracils	bromacil	Hyvar, Krovar[17]
Group 6 Photosystem II inhibitors (same site as group 5, but different binding characteristics)	benzothiadiazoles	bentazon	Basagran, Storm[18]
Group 7 Photosystem II inhibitors (same site as group 5 and 6, but different binding characteristics)	ureas	diuron	Direx, Diuron, Karmex, K4[16], Krovar[17]
		floumeturon	Cotoran
		linuron	Linex, Lorox
		tebuthiuron	Spike

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	amide	propanil	Duet[4], Stam
		napropamide	Devrinol
Group 8 Lipid synthesis inhibition (not ACCase inhibition)	thiocarbamates	butylate	Sutan
		EPTC	Eptam, Eradicane
		thiobencarb	Bolero
Group 9 EPSP synthase inhibitors	no family name	glyphosate	many
Group 10 Glutamine synthase inhibitors	no family name	glufosinate	Finale, Ignite
Group 12 Carotenoid biosynthesis inhibitors at phytoene desaturase	pyridazinone	norflurazon	Predict, Solicam, Zorial
Group 13 Bleaching: diterpene inhibitors	isoxazolidinone	clomazone	Command 3ME
Group 14 Protoporphyrinogen oxidase (PPO) inhibitors	aryl triazinone	carfentrazone	Aim, Power Zone[19]
	diphenylethers	acifluorfen	Storm[18], Ultra Blazer
		lactofen	Cobra, Phoenix
		oxyfluorfen	Galligan, Goal, Oxiflo
	N-phenylphtalimides	flumioxazin	Chateau, Sureguard, Valor SX
		flumiclorac	Resource
	oxadiazole	oxadiazon	Authority, Ronstar
	pyrazole	Pyraflufen	Edict IVM, ET
Group 15 unknown site of action	acetamides	napropamide	Devrinol
	chloroacetamides	acetochlor	Volley
		metolachlor	Bicep II Magnum[14], Dual Magnum, Lexar[15], Pennant Magnum
		pronamide	Kerb
	oxyacetamides	flufenacet	Axiom
Group 16 unknown site of action	benzofuran	ethofumesate	Prograss
Group 17 unknown site of action	organoarsenicals	MSMS	MSMA

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Group 18 DHP (dihydropteroate synthase step) inhibitors	carbamate	asulam	Asulox, Asulam
Group 19 Indoleacetic acid inhibitors	pthalamate	naptalam	Alanap
Group 21 Cell wall synthesis inhibitor (site B)	benzamide	isoxaben	Gallery
Group 22 Photosystem I electron diversion	bipyridyliums	paraquat	Gramoxone
Group 27 Hydroxyphenyl-pyruvate-dioxygenase inhibitors	triketone	mesotrione	Callisto, Lexar[15]

[1] Fusion is a commercial premix of fenoxaprop and fluazifop.
[2] Lightning is a commercial premix of imazapyr and imazethapyr.
[3] Pursuit Plus is a commercial premix of imazethapyr and pendimethalin.
[4] Duet is a commercial premix of bensulfuron and propanil.
[5] Yukon is a commercial premix of halosulfuron and dicamba.
[6] Landmark is a commercial premix of chlorsulfuron and sulfometuron.
[7] Synchrony is a commercial premix of chlorimuron and thifensulfuron.
[8] Oust Extra is a commercial premix of metsulfuron and sulfometuron.
[9] Harmony Extra is a commercial premix of thifensulfuron and tribenuron.
[10] Oustar and Westar are commercial premixes of sulfometuron and hexazinone.
[11] Outlaw and Trimec are commercial premixes of 2,4-D, dicamba, and MCCP.
[12] Confront and Redeem are commercial premixes of clopyralid and triclopyr.
[13] Pasturegard is a commercial premix of triclopyr and fluroxapyr.
[14] Bicep II Magnum is a commercial premix of atrazine and metolachlor.
[15] Lexar is a commercial premix of atrazine, metolachlor, and mesotrione.
[16] K4 is a commercial premix of hexazinone and diuron.
[17] Krovar is a commercial premix of bromacil and diuron.
[18] Storm is a commercial premix of bentazon and aciflourfen.
[19] Power Zone is a commercial premix of carfentrazone, dicamba, MCPA, and mecoprop.