Erratum for PNW 437
Herbicide-Resistant Weeds and Their Management

In the herbicide rotation chart, group 14, delete the following:

In the herbicide common name column: pyroxasulfone

In the herbicide trade names column: Fierce (contains flumioxazin) *Registration pending*

In the herbicide rotation chart, group 15, add the following:

In the herbicide chemical family column: isoxazolines

In the herbicide common name column: pyroxasulfone

In the herbicide trade names column: Fierce (contains flumioxazin), several others

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PNW 437

Herbicide-Resistant Weeds and Their Management

When planning a herbicide program to prevent resistance, do not use herbicides from the same group more than once within three years for the same weed species.

Herbicide-Resistance Basics

Herbicide resistance is the inherited ability of a plant to survive a herbicide application to which the original populations were susceptible. Resistant plants occur naturally within a population. They differ slightly in genetic makeup from the original populations, but they remain reproductively compatible with them.

Herbicide-resistant plants initially are present in a weed population in extremely small numbers (about 1 in 100,000 to more than 1 in 1,000,000). The repeated use of one herbicide, or of herbicides that kill the plants the same way (same site of action or same herbicide group), allows these few plants to survive and reproduce. The number of resistant plants then increases in the population until the herbicide no longer effectively controls it.

Resistant weed populations may persist in infested fields for many years, even without any additional selection pressure from the herbicide. There is no evidence that herbicides cause the genetic mutations that lead to herbicide resistance.

Types of resistance

Herbicides are organized into groups based on their site of action. Herbicides in the same group all kill plants the same way.

Weed populations may be resistant to herbicides in different chemical families if those families share the same site of action. For example, kochia populations in southern Idaho are resistant to imidazolinone and sulfonylurea herbicides, which are both in herbicide group 2. This is called *cross-resistance*.

Resistance to herbicides with different sites of action can also occur. For example, an Italian ryegrass biotype (a group of organisms having the same genotype) in Idaho is resistant to herbicides in at least three different groups: 1, 2, and 15. This is called *multiple resistance*.

Herbicide resistance should not be confused with the natural herbicide tolerance that some species have. For example, wheat is tolerant to Puma because it rapidly deactivates the herbicide. Wild oat can only slowly deactivate Puma, so Puma can be used to remove wild oat from a wheat field.

Herbicide resistance in the Pacific Northwest and worldwide

The first identified herbicide-resistant weed biotype, spreading dayflower (*Commelina diffusa*), which is resistant to 2,4-D, was identified in 1957 in a Hawaii sugarcane field. Since then, more than 350 weed biotypes resistant to one or more herbicides have been identified worldwide. Current information on the status of herbicide-resistant weeds can be found at http://weedscience.org/

A number of herbicide-resistant weed biotypes are now common in the Pacific Northwest:

- Kochia, prickly lettuce, Russian thistle, and many other broadleaf weeds are resistant to sulfonylurea (group 2) herbicides (e.g., Harmony Extra, Beyond, Everest).
- Wild oat and Italian ryegrass are resistant to Assure II and other ACCase inhibitor (group 1) herbicides.
- Powell amaranth and other pigweed species are resistant to triazines and other group 5 herbicides.
- Prickly lettuce is resistant to 2,4-D, dicamba, MCPA (group 4).
- Wild oat is resistant to Far-Go (group 8).
- Italian ryegrass is resistant to glyphosate (group 9), glufosinate (group 10), and flufenacet (group 15).

This publication contains the

Guide for Herbicide Rotation

reference poster

Planning Your Herbicide Program

The development of herbicide-resistant weed populations is strongly linked to repeated use of the same herbicide or of herbicides with the same site of action in monoculture cropping systems and in noncrop areas such as railway or road rights-of-way. However, herbicides with the same site of action can also be used in different crops grown in a rotation. Therefore, knowing the chemical family and site-of-action group in which a herbicide belongs *and* knowing which other herbicides have the same site of action are critical for creating a plan to prevent or delay development of herbicide-resistant weed populations.

The herbicide rotation table inside this publication lists herbicides by site-of-action group and gives a number and color code to each group to help in distinguishing among them. The table also gives each herbicide's chemical family, common name, and trade name and gives examples of confirmed resistant weed populations by state.

When planning a herbicide program to prevent or delay resistance, do not use herbicides from the same site-of-action group more than once within three years!

Preventing or delaying herbicide resistance

Multiple management practices can be used in an integrated plan to prevent or delay the development of herbicide-resistant weed populations. Use the following practices along with the herbicide-rotation table to form an effective herbicide resistance management strategy.

Rotating herbicides—Avoid year-after-year use of the same herbicide or of herbicides with the same site of action. Remember that herbicides belonging to different chemical families may have the same site of action. For example, Maverick is a sulfonylurea herbicide and Pursuit is an imidazolinone herbicide, but both are group 2 herbicides.

Rotating crops—Crops differ in their competitiveness against weeds based on life cycle, growth habit, maturity length, etc., so rotating to different crops can help prevent some weed species from becoming dominant in a given field. In addition, because different crops may require different types of herbicides, rotating crops can enable herbicide rotation.

However, some herbicide groups include many different herbicides available for use in many different crops, the imidazolinones and sulfonylureas in group 2, for example. In these cases, crop rotation alone may not be enough to avoid resistance development. In addition, avoid using herbicides with the same site of action in both fallow years and in the crop(s) planted within 3 years.

Using short-residual herbicides—Using herbicides that do not persist in soil for long time periods and not applying them repeatedly within a growing season reduces the selection of herbicide-resistant weed biotypes. However, repeated applications within a single growing season of paraquat, a herbicide with no soil activity, has resulted in the development of paraquat-resistant weed populations. Similar situations have occurred with glyphosate.

Cultivating—Cultivation in row crops can eliminate weed escapes, which may be resistant biotypes. Fallow tillage can control herbicide-resistant and herbicide-susceptible weed populations equally as long as seedlings of the two biotypes emerge at about the same time.

Accurate record keeping—You must know which herbicides and herbicide sites of action have been used in the past, at what rates, and how often. Also keep track of the weed species that have been present in a given field and of how well particular herbicides have controlled them.

Planting clean seed—Plant certified seed to greatly minimize the introduction of weed seeds from herbicide-resistant biotypes. (Certified seed may contain some weed seeds, but not those of noxious weeds.)

Practicing integrated weed management—Integration of many control practices is important for effective control of all weeds, not just for herbicide-resistance management. Integrated weed management uses all the tools available to control weeds, including cultural, mechanical, and chemical methods. An integrated approach to weed management, whether in crop or noncrop land, is an important environmental and economic consideration.

Tank-mixing in resistance management

Tank-mixing herbicides with different sites of action is not always an effective resistance management strategy. Weed control spectrums of the different herbicides in the mixture must overlap so that weed biotypes resistant to one site of action are controlled by a herbicide with a different site of action. If not, then resistant biotypes can survive and eventually dominate the population.

In addition, if the herbicides in the tank mixture have different soil residual characteristics, resistant weed biotypes can still be selected. For example, Glean and 2,4-D have different sites of action; however, Glean is a long-residual herbicide and 2,4-D is a short-residual herbicide. When tank-mixed, both herbicides control some of the same broadleaf weed species shortly after application. However, Glean will continue to control weeds long after the 2,4-D has stopped providing control, and selection for weed biotypes resistant to Glean could therefore be occurring.

Unless the control spectrum overlaps and the residual length is similar, avoid repeated use of a herbicide or of a herbicide site of action *even in tank mixtures with other site-of-action herbicides*. Exceptions can be made when a specific herbicide combination is required to control the weed spectrum present or when tank-mixing will result in reduced herbicide use rates. Tank-mixing for other reasons is not economically or ecologically sound.

Dealing with herbicide resistance

Monitoring fields for weed escapes—Weed escapes may or may not be resistant biotypes. A resistance problem may not become visible until 30 percent or more of the weed population is no longer controlled. Check to see if the escapes are of one species or a mixture of species. If a mixture, the problem is more likely related to the environment or the herbicide application. If only one species was not controlled, the problem is more apt to be resistance, especially if the species was controlled by the herbicide in the past and if the same herbicide has been used repeatedly in the field.

Preventing weed spread—Prevent weeds in a herbicide-resistant population from flowering and producing seed if possible. Thoroughly clean machinery used in fields or areas with known or suspected infestations of herbicide-resistant weed populations before moving the machinery to other fields or areas. Always plant certified crop seed, free of weed seeds.

Rotating crops and tillage systems—Rotating crops and using differing tillage practices and timings can affect weed populations. Alternating spring and winter crops, for example, means that a field will be tilled and sometimes sprayed with herbicides at different times in the different crops. Resistant as well as susceptible weed biotypes that survive in one type of crop with its associated application and tillage timings could be killed in the other type of crop.

Changing herbicide program—If weed resistance occurs, herbicides with other sites of action and other weed management practices must be used in an integrated management strategy.

Recognizing herbicide resistance

Irregularly shaped patches of a single weed species in a field are an indicator of herbicide resistance, especially when

- There are no other apparent application problems.
- Other weed species are controlled adequately.
- No or minimal herbicide symptoms appear on the single uncontrolled weed species.
- There has been a previous failure to control the same species in the same field with the same herbicide or with herbicides with the same site of action.
- Records show repeated use of one herbicide or of herbicides with the same site of action.

What to do if you suspect herbicide resistance

- Do not respray the field with the same herbicide or with herbicides with the same site of action.
- Report your suspicion to a university researcher or extension specialist or to the extension educator in your county.
- If possible, collect plants or seed that can be used to confirm resistance has developed. However, controlling weed escapes and preventing production of viable seeds are of prime importance.

Managing herbicide-resistant crops

Herbicide-resistant crops have recently been developed for use in weed control. These crops are resistant to herbicides that are lethal to susceptible varieties of the same crop.

Crops resistant to specific herbicides have been developed both through genetic engineering and through traditional selective breeding. Examples include Clearfield wheat, which was selected for resistance to imazamox, and Roundup Ready canola, field corn, and sugarbeets, which were genetically engineered to be glyphosate-resistant.

Used properly, herbicide-resistant crops can be valuable tools for managing difficult-to-control weeds. They also have two inherent risks that need to be considered prior to planting: (1) the emergence of herbicide-resistant volunteers in subsequent growing seasons and (2) the potential for herbicide-resistant crops to cross with weedy relatives. Also, they provide a potential use for the same herbicide several times a year and season after season.

Volunteer herbicide-resistant crops as weeds—Consider whether the herbicide-resistant crop typically occurs as a volunteer crop in subsequent growing seasons, and, if so, whether effective control options are available in the crop rotation to remove herbicide-resistant volunteers. For example, glyphosate, the active ingredient in Roundup, is commonly used to control volunteer crops prior to planting a rotational crop. Glyphosate will not effectively control Roundup Ready crops, however, so some other herbicide or nonchemical control measure will be required to control the glyphosate-resistant volunteers.

Evaluate the impacts on your operation of using these other herbicides or nonchemical control measures against the impacts of not using the herbicide-resistant crop. Impacts could be increased cost, increased soil erosion, moisture loss due to increased tillage, or other factors.

Volunteer crops are usually considered to be a problem largely within one year of harvest. However, certain species have extended dormancy, which could result in multiple years of a herbicide-resistant volunteer crop problem even without seed production by the volunteer plants.

Gene-flow from herbicide-resistant crops to weedy relatives—In rare instances, the trait conferring herbicide resistance in a crop moves into weedy relatives through cross-pollination, resulting in a herbicide-resistant weed. Consider weedy and native relatives of the herbicide-resistant crop in the surrounding area as well as their propensity to cross-pollinate. Self-pollinating crops, such as soybean, are considered low risk in terms of gene flow to weeds or other crops. Roundup Ready, Clearfield, or Liberty Link canola, in contrast, could pollinate nearby herbicide-susceptible canola as well as weedy canola relatives, resulting in volunteer canola plants and weeds that may be resistant to several herbicide families.

Herbicide-resistant cropping systems at risk for gene flow or volunteer management problems may have some or all of the following traits:

- The crop cross-pollinates with other nearby crops or with relatives that are problem weeds.
- The crop seed shatters at or before harvest, as with canola, or leaves vegetative propagules in the ground after harvest, as with potatoes, resulting in volunteer crops in subsequent years.
- Herbicides available for managing volunteer crops are limited to the same herbicide site-of-action group to which the crop is resistant.
- Crop seed remains viable in the soil for several cropping seasons.

Use of a herbicide-resistant crop can increase your reliance on a herbicide within a site-of-action group. The same herbicide may be applied multiple times per season and/or several times during a cropping system rotation.

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ALWAYS read and follow the instructions printed on the pesticide label. The pesticide recommendations in this publication do not substitute for instructions on the label. Pesticide laws and labels change frequently and may have changed since this publication was written. Some pesticides may have been withdrawn or had certain uses prohibited. Use pesticides with care. Do not use a pesticide unless the specific plant, animal, or other application site is specifically listed on the label. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

Trade Names—To simplify information, trade names have been used. No endorsement of named products is intended nor is criticism implied of similar products not mentioned.

Groundwater—To protect groundwater, when there is a choice of pesticides, the applicator should use the product least likely to leach.

Add this publication to your Pacific Northwest Conservation Tillage Handbook in chapter 5, "Weed Control Strategies," as series #18.

Pacific Northwest extension publications are produced cooperatively by the three Pacific Northwest land-grant universities: Washington State University, Oregon State University, and the University of Idaho. Similar crops, climate, and topography create a natural geographic unit that crosses state lines. Since 1949, the PNW program has published more than 550 titles, preventing duplication of effort, broadening the availability of faculty specialists, and substantially reducing costs for the participating states.

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Guide for Herbicide Rotation in the Pacific Northwest

To avoid selecting for herbicide-resistant weeds, do not use herbicides from the same color group more than once within three years. Rather, rotate to a different group every year of the production system.

Herbicide group number and site of action	Herbicide chemical family	Herbicide common name	Herbicide trade names	Resistant weeds in the PNW	States with resistant weeds
Group 1 Acetyl CoA carboxylase (ACCase) inhibitors	cyclohexane-diones	clethodim	Select Max, Envoy, several others	Italian ryegrass Downy brome	ID, WA
		sethoxydim	Poast, several others	Italian ryegrass	ID, WA
				Downy brome	OR
		tralkoxydim	Achieve	Italian ryegrass	ID, WA
	aryloxyphenoxy-propanoates	clodinafop	Discover NG	Italian ryegrass	ID,WA
				Wild oat	ID
		diclofop	Hoelon	Wild oat	ID, OR, WA
				Italian ryegrass	ID, OR, WA
		fenoxaprop	Puma, others	Wild oat	ID, OR
		fluazifop	Fusilade DX	Downy brome	OR
		quizalofop	Assure II, Targa	Italian ryegrass	ID, WA
				Downy brome	OR
	phenylpyrazoline	pinoxaden	Axial	Italian ryegrass	ID, OR, WA
Group 2 Acetolactate synthase (ALS) inhibitors	imidazolinones	imazamox	Raptor, Beyond, Clearmax (Beyond + MCPA)	Downy brome	OR
				Spiny sowthistle	WA
		imazapic	Plateau, others		
		imazapyr	Arsenal, Chopper, several others		
		imazethapyr	Pursuit, others	Prickly lettuce	ID
				Kochia	ID
				Spiny sowthistle	ID
				Black mustard	ID
				Mayweed chamomile	ID
	sulfonylureas	chlorsulfuron	Glean, Telar	Prickly lettuce	ID, OR, WA
				Kochia	ID, OR, WA
				Russian thistle	ID, OR, WA
				Italian ryegrass	OR
				Mayweed chamomile	ID, WA
				Smallseed falseflax	OR
		halosulfuron	Sandea, others		
		mesosulfuron	Osprey	Italian ryegrass	ID, WA
		mesosulfuron/ propoxycarbazone	Olympus Flex		
		metsulfuron	Ally, Escort, Cimarron, others	Prickly lettuce	ID, OR
				Kochia	OR
				Russian thistle	OR
				Smallseed falseflax	OR
		nicosulfuron	Accent, others		
		primisulfuron	Beacon, others	Downy brome	OR
		prosulfuron	Peak, Spirit		
		rimsulfuron	Matrix, others		
		sulfometuron	Oust, others		
		sulfosulfuron	Maverick, Outrider, Certainty	Downy brome	OR
		thifensulfuron	Harmony, others	Spiny sowthistle	WA
				Prickly lettuce	ID
				Mayweed chamomile	ID
		thifensulfuron/ tribenuron	Harmony Extra, Affinity		
		triasulfuron	Amber, others	Prickly lettuce	ID, OR
				Kochia	OR
				Russian thistle	OR
				Italian ryegrass	ID, WA
		tribenuron	Express, others	Prickly lettuce	ID
				Mayweed chamomile	ID
		triflusulfuron	UpBeet		
	sulfonylamino-carbonyl-triazolinones	flucarbazone	Everest, others	Italian ryegrass	ID, WA
		propoxycarbazone	Olympus		
	triazolo-pyrimidines	florasulam	Orion (contains MCPA), others		
		pyroxsulam	GoldSky (contains florasulam & fluroxypyr), PowerFlex		
Group 3 Microtubule assembly inhibitors	dinitroanalines	benefin	Balan, others		
		ethalfluralin	Sonalan, others		
		oryzalin	Surflan, others		
		pendimethalin	Prowl H_2O, Pendulum, several others		
		prodiamine	Barricade, Endurance, several others		
		trifluralin	Treflan, others		
	benzamides	pronamide	Kerb	Wild oat	OR
Group 4 Synthetic auxins	phenoxy acetic acids	2,4-D	several	Prickly lettuce	WA
		2,4-DB	several		
		MCP	several	Prickly lettuce	WA
		mecoprop (MCPP)	several		
	benzoic acids	dicamba	Banvel, Clarity, several others	Kochia Prickly lettuce	ID WA
	pyridines	aminopyralid	Milestone, several		
		clopyralid	Stinger, others		
		fluroxypyr	Starane, others		
		picloram	Tordon K, Tordon 22K	Yellow starthistle	WA
		triclopyr	Garlon, Remedy, Renovate		
	quinoline carboxylic acids	quinclorac	Paramount, Drive, others		

Herbicide group number and site of action	Herbicide chemical family	Herbicide common name	Herbicide trade names	Resistant weeds in the PNW	States with resistant weeds
Group 5 Photosystem II inhibitors (groups 5, 6, and 7 have the same site but different binding behavior)	triazines	atrazine	AAtrex, others	Common lambsquarters	ID, OR, WA
				Pigweed spp.	ID
				Common groundsel	OR, WA
				Annual bluegrass	OR
				Kochia	ID
		simazine	Princep, Simazine	Common groundsel	WA
	as-triazines	hexazinone	Velpar, others	Shepherd's purse	OR
		metribuzin	Sencor, others	Shepherd's purse	OR
				Redroot pigweed	ID
	uracils	bromacil	Hyvar X, others		
		terbacil	Sinbar	Common groundsel	OR
				Pigweed spp.	OR, WA
				Common lambsquarters	OR
Group 6 Photosystem II inhibitors (see group 5)	benzothia-diazoles	bentazon	Basagran		
	nitriles	bromoxynil	Buctril, Bronate (contains MCPA), several others	Common groundsel	OR
Group 7 Photosystem II inhibitors (see group 5)	ureas	diuron	Karmex, Direx, others	Common lambsquarters	OR
				Annual bluegrass	OR
		linuron	Lorox, Linex		
		tebuthiuron	Spike, others		
Group 8 Lipid synthesis inhibitors but not ACCase inhibitors	thiocarbamates	cycloate	Ro-Neet		
		EPTC	Eptam, Imperium *(Imperium is not registered in OR)*		
		EPTC + safener	Eradicane		
		triallate	Far-Go, Avadex, Buckle	Wild oat	ID
Group 9 EPSP synthase inhibitors	glycines	glyphosate	Roundup, several others	Italian ryegrass	OR
Group 10 Glutamine synthase inhibitors	phosphinic acids	glufosinate	Rely, Liberty, several others	Italian ryegrass	OR
Group 14 Inhibitors of protopor-phyrinogen oxidase (Protox)	diphenylethers	oxyfluorfen	Goal, several others		
	N-phenyl-phthalimides	flumiclorac	Resource		
		flumioxazin	Chateau, Valor, others		
	aryl-triazinones	carfentrazone	Aim, several others		
		sulfentrazone	Spartan, others		
	pyrazoles	pyraflufen	ET, Edict		
		pyroxasulfone	Fierce (contains flumioxazin) *Registration pending*		
	pyrimidinedione	saflufenacil	Sharpen		
	thiadiazole	fluthiacet	Cadet		
Group 15 Inhibitors of very-long-chain fatty acid synthesis	chloroacet-amides	acetochlor	Harness, Surpass, several others		
		alachlor	MicroTech, several others		
		dimethenamid(-p)	Outlook, others		
		metolachlor	Stalwart, Dual, others		
	oxyacetamides	flufenacet	Axiom (contains metribuzin), Define	Italian ryegrass	ID, OR, WA
	acetamides	napropamide	Devrinol		
Group 16 Unknown	benzofuranes	ethofumesate	Nortron, several others	Annual bluegrass	OR
Group 17 Unknown	organo-arsenicals	MSMA	several		
Group 20 Inhibitors of cell wall synthesis site A	nitriles	dichlobenil	Casoron, others		
Group 22 Photosystem I electron diverters	bipyridiliums	diquat	Reglone, others		
		paraquat	Gramoxone Inteon, several others		
Group 26 Unknown	carboxylic acids	pelargonic acid	Scythe, others		
Group 27 Inhibitors of 4-HPPD*	isoxazoles	pyrasulfotole	Huskie (contains bromoxynil)		
	triketones	mesotrione	Callisto, others		
		topramezone	Impact, Frequency		

* 4-hydroxyphenylpyruvatedioxygenase