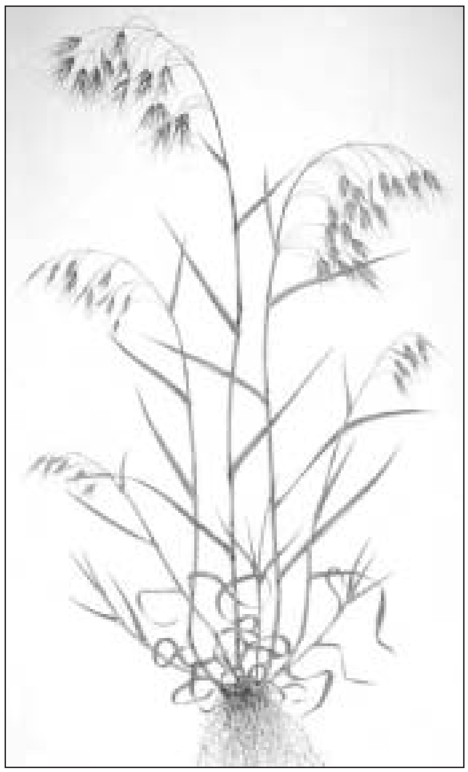
PNW 572

Management Strategies for Preventing Herbicide-Resistant Grass Weeds in Clearfield Wheat Systems

By Curtis Rainbolt, Dan Ball, Donn Thill, and Joe Yenish



Wild oat
Downy brome
Jointed goatgrass

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The authors—Curtis Rainbolt, former Weed Science Graduate Student, University of Idaho; currently Extension Agent II, University of Florida Extension; Dan Ball, Weed Scientist, Oregon State University; Donn Thill, Weed Scientist, University of Idaho; Joe Yenish, Extension Weed Scientist, Washington State University

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Introduction

The Clearfield (imidazolinone-resistant) winter wheat production system is currently available in the Pacific Northwest (PNW). Imazamox (Beyond), a group 2 (ALS inhibitor) herbicide, applied to Clearfield winter wheat provides an unprecedented opportunity to selectively control jointed goatgrass. The system can also be used to control other grass weeds, such as downy brome and wild oat. However, overuse of this technology will rapidly result in the selection of weed populations that are resistant to group 2 herbicides.

Many group 2 herbicides (sulfonylureas, imidazolinones, sulfonylaminocarbonyltriazolinones, and others ALS-inhibiting herbicides; see table 1) already are used extensively in wheat cropping systems, and some broadleaf weeds have developed resistance to several of the sulfonylurea herbicides used for broadleaf weed control. (See PNW 437, *Herbicide-Resistant Weeds and Their Management*.) Imazamox applied to Clearfield winter wheat will only increase group 2 herbicide use for grass weed control, especially in crop rotations where winter wheat is grown frequently.

Table 1. Group 1, 2, and 8 herbicides commonly used in inland Pacific Northwest winter wheat cropping systems.

Group number and site of action	Chemical family	Common name	Trade name
Group 1 Acetyl CoA carboxylase (ACCase) inhibitors	cyclohexanediones	clethodim	Select
		tralkoxydim	Achieve
		sethoxydim	Poast
	aryloxyphenoxy propanoates	diclofop	Hoelon
		clodinafop	Discover
		fenoxaprop	Puma
		quizalofop	Assure II
Group 2 Acetolactate synthase (ALS) inhibitors	imidazolinones	imazamethabenz	Assert
		imazethapyr	Pursuit
		imazamox	Beyond
	sulfonylureas	chlorsulfuron	Glean
		metsulfuron	Ally
		sulfosulfuron	Maverick
		thifensulfuron	Harmony
		tribenuron	Express
	sulfonylamino-carbonyltriazolinones	flucarbazone-sodium	Everest
		propoxycarbazone	Olympus
Group 8 Lipid synthesis inhibitors	thiocarbamates	triallate	Far-Go
Unknown site of action	no family name	difenzoquat	Avenge

Group 2 herbicides are more prone to select for resistant weed populations than herbicides from other groups because several naturally occurring genetic mutations in the target weeds can produce resistant biotypes. Based on the number of weed seeds present in most fields, it can be assumed that small populations of group 2-resistant weeds are already present in some fields even if they have never been sprayed with group 2 herbicides. In most cases herbicide-resistant populations go undetected until they represent about 30% of the total population because weed control is rarely 100%.

A computer model was developed at the University of Idaho to predict the ratio of susceptible to resistant weed seeds in the soil seed bank over time under the influences of herbicide and crop rotation; seed germination; seedling mortality; herbicide-induced mortality/control; seed production; seed loss from predation, removal at harvest, and decay; initial seed bank density; and the naturally occurring frequency of group 2 herbicide resistance. Modeling results were used to develop herbicide rotation strategies for PNW dryland cropping systems where Clearfield wheat is used as a weed management tool. Computer modeling was used because it provided a timely method for comparing the long-term effects of management strategies. However, the strategies recommended in this publication have never been tested in the field.

The Clearfield production system for winter wheat will be a valuable weed management tool. Judicious use of group 2 herbicides is key to preventing the selection of group 2-resistant weed populations.

Model simulations

Fifteen different scenarios (table 2) were modeled to predict downy brome, jointed goatgrass, and wild oat populations in the major winter wheat cropping systems of the inland PNW. Continuous annual Clearfield wheat represented the

Table 2. Scenarios used in the herbicide-resistant weed prediction model for Clearfield winter wheat production in the inland PNW.

Weed species/ rotation	Precipitation zone[1]
Downy brome	
Continuous annual Clearfield	-
Clearfield - fallow	low
Clearfield - fallow - winter wheat - fallow	low
Clearfield - spring wheat	intermediate
Clearfield - spring wheat - winter wheat – spring wheat	intermediate
Jointed goatgrass	
Continuous annual Clearfield	-
Clearfield - fallow	low
Clearfield - fallow - winter wheat - fallow	low
Clearfield - spring wheat	high/intermediate
Clearfield - spring wheat - spring pea	high
Clearfield - spring wheat - spring pea - winter wheat spring wheat - spring pea	high
Wild oat	
Continuous annual Clearfield	-
Clearfield™ - spring wheat	high/intermediate
Clearfield™ - spring wheat - spring pea	high
Clearfield™ - spring wheat - spring pea - winter wheat - spring wheat - spring pea	high

Note: Winter wheat crops, other than Clearfield, are treated with herbicides other than those in group 2.

[1] Low is less than 12 inches, intermediate is 13 to 19 inches, and high is greater than 20 inches of annual precipitation.

worst-case management scenario. In most cases, conservative data or estimates were used in an attempt to keep the model realistic. However, it is very important to note that in some fields the initial seed bank density, natural frequency of herbicide resistance (mutation rate), and other factors may be considerably higher, resulting in faster selection of herbicide-resistant weed populations.

Assumptions

Annual seed germination rate and annual seed production per plant were estimated to be 30% (high seed dormancy) and 50 seeds per plant (low seed production) for wild oat. For jointed goatgrass, the seed germination rate was 50% (moderate seed dormancy) and seed production was 75 seeds per plant (moderate seed production). The germination rate was 85% (low seed dormancy) and seed production was 150 seeds per plant (high seed production) for downy brome.

Control of susceptible biotypes with imazamox was estimated at 95% for jointed goatgrass and wild oat and 98% for downy brome, while resistant biotypes were not susceptible and were not controlled. In fallow years control of all biotypes was assumed to be 100% with tillage, burndown herbicides, or a combination of both.

In years where an alternate crop and an alternate mode-of-action herbicide (non-group 2) were used, wild oat control was estimated to be 95% in spring wheat, 99% in spring peas, and 95% in standard (non-Clearfield) winter wheat. Jointed goatgrass is typically not a problem in spring crops, and control was estimated to be 98% in spring wheat and spring peas. Jointed goatgrass was not controlled in standard winter wheat years. Downy brome control in spring wheat was estimated to be 98%, and in standard winter wheat control was estimated to be 75%.

Downy brome: Simulated results and management

Continuous annual Clearfield winter wheat

Simulated continuous annual Clearfield winter wheat and imazamox herbicide use resulted in a rapid increase of resistant seed in the soil seed bank. By year 6 the total number of downy brome seeds in the soil exceeded the initial population (figure 1-A). The ability of downy brome to produce many non-dormant seeds results in large numbers of seedlings being exposed to herbicide selection pressure, which greatly increases the likelihood of selecting resistant biotypes. Thus, continuous annual use of Clearfield winter wheat treated with imazamox or standard winter wheat treated with other group 2 herbicides for control of downy brome is a very poor weed management strategy.

Low precipitation zone rotations

In year 9 of the Clearfield winter wheat-fallow simulation, the total soil seed bank was about 0.05% of the initial soil seed bank (figure 1-B) compared with about 0.2% in year 9 of the Clearfield winter wheat-fallow-standard winter wheat-fallow simulation (figure 1-C). However, including a standard winter wheat crop in the rotation—and not using another group 2 herbicide—resulted in the resistant soil seed bank increasing at a much slower rate.

Management strategies—In low-precipitation-zone fields with serious downy brome infestations, it may be advisable to use Clearfield winter wheat or other group 2 herbicides for two out of the first four years to reduce the population to a manageable level. In following years, a rotation that uses Clearfield winter wheat less frequently can keep the population in check while minimizing selection of resistant plants.

To test this management scheme, we simulated a six-year Clearfield winter wheat-fallow-Clearfield winter wheat-fallow-standard winter wheat-fallow rotation followed by a Clearfield winter wheat-fallow-standard winter wheat-fallow rotation for nine years. After the first six years the soil seed bank was 99.6% smaller than the initial soil seed bank and fewer than 1% of the remaining seeds were resistant. By year 15 the total soil seed bank was 99.95% smaller than initially.

Fields with dense populations of downy brome have more seeds and, consequently, a greater chance for selection of resistant biotypes. In these situations, it is sound management initially to use Clearfield winter wheat frequently to reduce the population—perhaps for two or three out of the first six years. This does increase selection pressure for resistance, but also quickly reduces the weed population, which may be an acceptable tradeoff.

Intermediate precipitation zone rotations

In the Clearfield winter wheat-spring wheat simulation (figure 1-D), the resistant soil seed bank surpassed the susceptible soil seed bank in seven years compared with 10 years in the Clearfield winter wheat-spring wheat-standard winter wheat-spring wheat simulation (figure 1-E). The resistant soil seed bank increased faster in the intermediate precipitation than in the low precipitation simulations because the intermediate precipitation simulations do not include fallow years, where control is 100%, but rather achieve 98% control in spring wheat years.

Management strategies—Downy brome can become a major problem in any rotation that includes frequent winter crops. Growing consecutive spring crops in intermediate precipitation zone rotations will greatly reduce the number of downy brome seeds in the soil seed bank. Reducing the initial seed bank density of downy brome prior to beginning a rotation that includes Clearfield winter wheat can reduce the likelihood of selecting herbicide-resistant biotypes.

In a simulation of two consecutive spring crops, the initial susceptible soil seed bank fell approximately 81%. In year 15 of a simulation of two spring crop years followed by a Clearfield winter wheat-spring wheat-standard winter wheat-spring wheat rotation, the resistant soil seed bank was about 10 times smaller than in the Clearfield winter wheat-spring wheat-standard winter wheat-spring wheat simulation.

Downy Brome: Results of simulated rotations

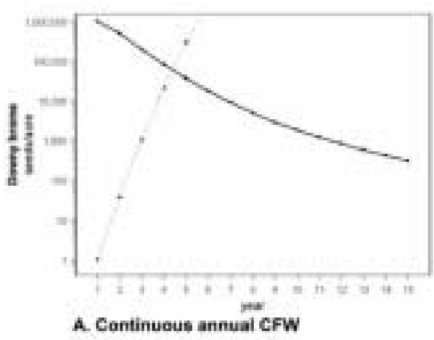
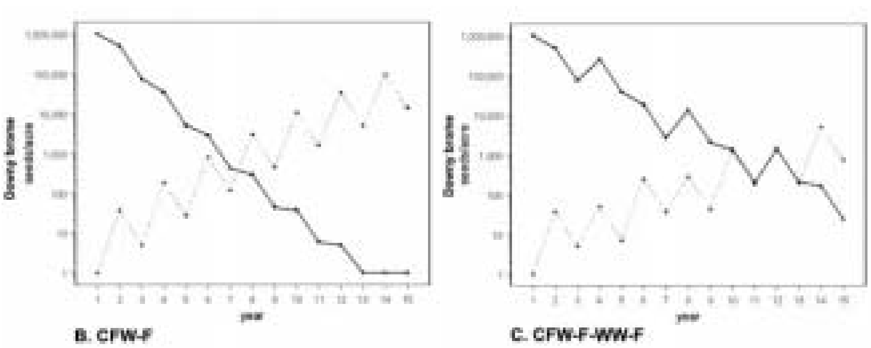
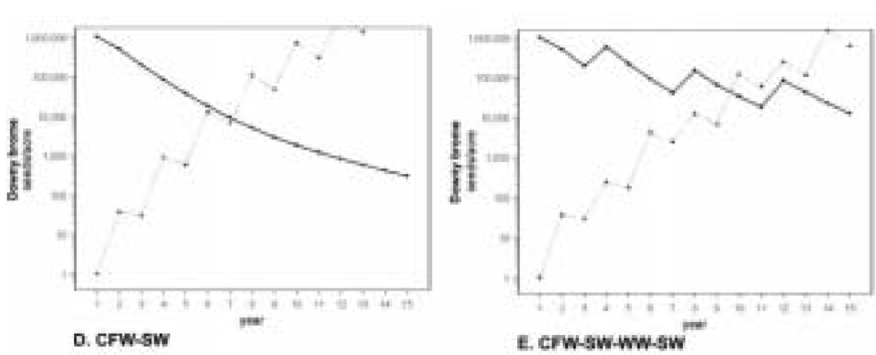


Figure 1. Downy brome seed bank under various simulated rotations: (A) continuous annual Clearfield winter wheat, (B) Clearfield winter wheat-fallow, (C) Clearfield winter wheat-fallow-standard winter wheat-fallow, (D) Clearfield winter wheat-spring wheat, and (E) Clearfield winter wheat-spring wheat-standard winter wheat-spring wheat. *Note the seeds/acre axis is logarithmic.*

Low precipitation zone simulations



Intermediate precipitation zone simulations



Jointed goatgrass: Simulated results and management

Continuous annual Clearfield winter wheat

Simulated continuous annual use of Clearfield winter wheat and imazamox herbicide resulted in the resistant jointed goatgrass soil seed bank surpassing the susceptible soil seed bank in year 7 (figure 2-A). The total soil seed bank was 80% smaller than the initial total soil seed bank in year 6, but by year 9 was more than twice the initial total soil seed bank. This clearly demonstrates that continuously growing Clearfield winter wheat is a poor strategy for reducing severe jointed goatgrass infestations.

Low precipitation zone rotations

In year 11 of the Clearfield winter wheat-fallow simulation, the total soil seed bank was about 99% smaller than the initial seed bank. However, by year 12 the resistant soil seed bank surpassed the susceptible soil seed bank, which resulted in an increase in the total soil seed bank (figure 2-B). In the Clearfield winter wheat-fallow-standard winter wheat-fallow simulation (figure 2-C), the resistant soil seed bank never exceeded the susceptible soil seed bank. However, because no herbicides control resistant (or susceptible) jointed goatgrass in standard winter wheat years, the resistant soil seed banks were identical for these two rotations. The lack of control in standard winter wheat years also caused the susceptible soil seed bank to decline slower in the Clearfield winter wheat-fallow-standard winter wheat-fallow rotation than in the Clearfield winter wheat-fallow rotation.

Management strategies—Winter wheat-fallow is currently the most economically feasible rotation in lower precipitation zones, and, consequently, jointed goatgrass control options are limited. Based on our simulations, the only effective rotation for reducing the total soil seed bank of jointed goatgrass in low precipitation areas is a Clearfield winter wheat-fallow rotation. This rotation does, however, impose high selection pressure for resistance. Once a group 2-resistant jointed goatgrass plant is selected, it likely will remain in the population because no other herbicides control jointed goatgrass in standard winter wheat crops. Fallow is then the only opportunity to control resistant biotypes. However, control in fallow is difficult because jointed goatgrass seeds produced in a single year survive and germinate over a period of one to five or more years. When possible, strategies for reducing jointed goatgrass populations should include spring crops or winter canola/rapeseed/mustard crops that can be sprayed with group 1 herbicides.

High precipitation zone rotations

In the Clearfield winter wheat-spring wheat simulation, the resistant soil seed bank surpassed the susceptible soil seed bank in year 12 (figure 2-D), which is similar to the outcome of the low precipitation Clearfield winter wheat-fallow simulation. However, the total number of seeds in the high precipitation zone simulation was almost four-fold higher, because jointed goatgrass control in spring wheat was estimated to be 98% compared with 100% during fallow years.

The resistant soil seed bank never exceeded the susceptible soil seed bank in the Clearfield winter wheat-spring wheat-spring pea rotation (figure 2-E) or in the Clearfield winter wheat-spring wheat-spring pea-standard winter wheat-spring wheat-spring pea rotation (figure 2-F). The jointed goatgrass seed population was reduced 99.5% by year 15 of the Clearfield winter wheat-spring wheat-spring pea rotation and 94% by year 15 of the Clearfield winter wheat-spring wheat-spring pea-standard wheat-spring wheat-spring pea rotation.

Management strategies—Jointed goatgrass is a winter annual and germinates primarily in the fall. Consequently, jointed goatgrass tends to be more of a problem in two-year winter wheat-spring crop rotations than in rotations that include two or more years of spring crops. Spring crops, particularly when combined with later seeding dates, are an effective means to control jointed goatgrass in higher precipitation zones.

A simulation of two consecutive spring crops reduced the initial jointed goatgrass populations approximately 65%. Reducing the jointed goatgrass population prior to using Clearfield winter wheat lessens the chance of selecting a resistant biotype. Growing consecutive spring crops is the best management in situations where the initial jointed goatgrass population is high because doing so can quickly reduce the population without selecting resistant biotypes.

Clearfield winter wheat should be managed carefully, because until a new herbicide (non-group 2) is available to

Jointed goatgrass: Results of simulated rotations

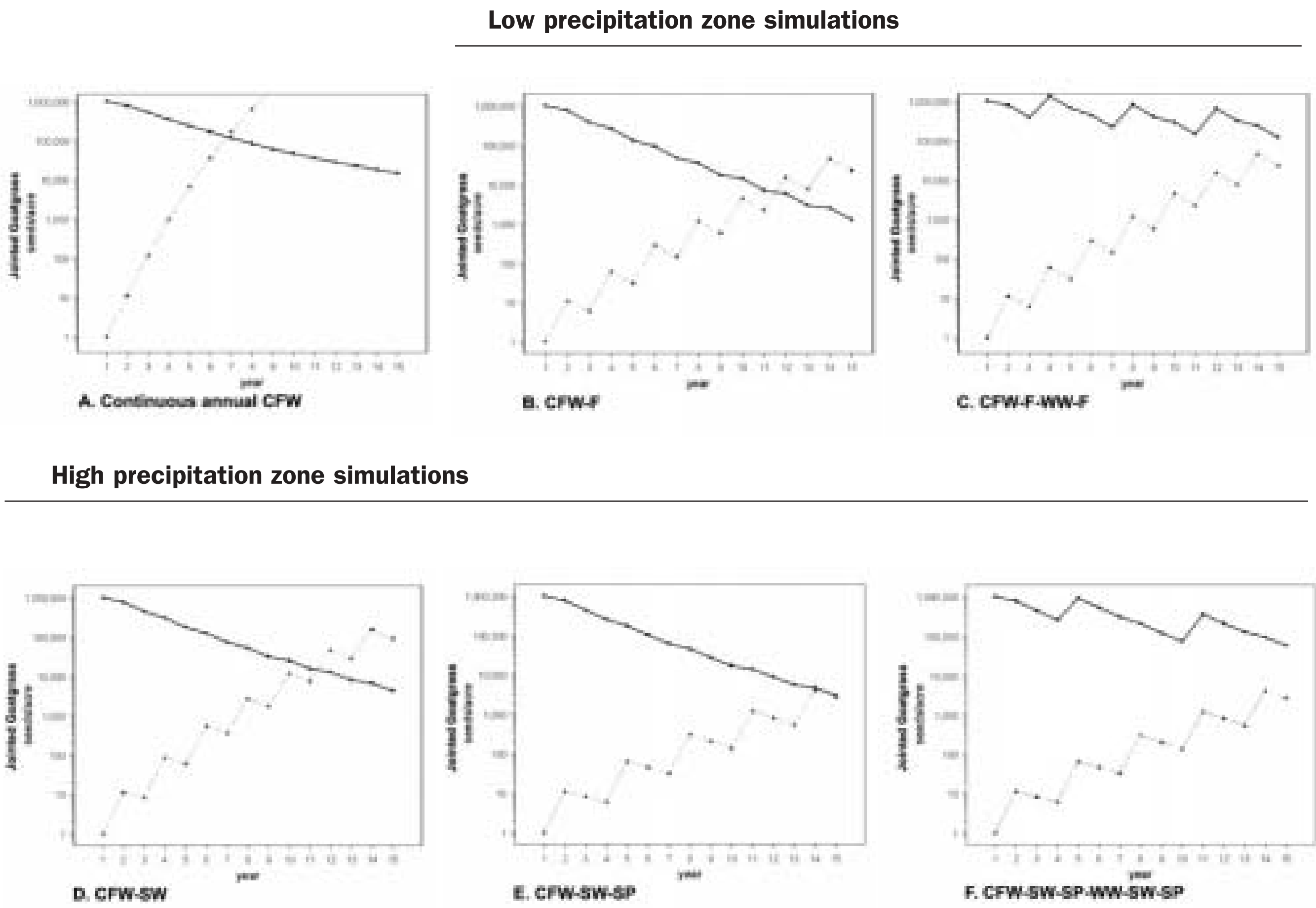


Figure 2. Jointed goatgrass seed bank under various simulated rotations: (A) continuous annual Clearfield winter wheat, (B) Clearfield winter wheat-fallow, (C) Clearfield winter wheat-fallow-standard winter wheat-fallow, (D) Clearfield winter wheat-spring wheat, (E) Clearfield winter wheat-spring wheat-spring pea, and (F) Clearfield winter wheat-spring wheat-spring pea-standard winter wheat-spring wheat-spring pea. *Note the seeds/acre axis is logarithmic.*

selectively control jointed goatgrass in winter wheat, group 2-resistant jointed goatgrass biotypes can only be controlled with tillage, spring crops, or winter-sown broadleaf crops.

Wild oat: Simulated results and management

Continuous annual Clearfield winter wheat

Simulated continuous annual use of Clearfield wheat and imazamox resulted in the resistant soil seed bank surpassing the susceptible soil seed bank in year 10. By year 15 the total soil seed bank was 9.3 times larger than the initial total soil seed bank (figure 3-A).

Intermediate/high precipitation zone rotations

The resistant soil seed bank never surpassed the susceptible soil seed bank in simulations of Clearfield winter wheat in rotation with spring wheat (figure 3-B), with spring wheat and spring pea (figure 3-C), or with spring wheat, spring peas, and standard winter wheat (figure 3-D). By year 15 of the Clearfield winter wheat-spring wheat simulation, the total soil seed bank was approximately 95% smaller than the initial soil seed bank. However, about 17% of the total soil seed bank was herbicide resistant.

In both the Clearfield winter wheat-spring wheat-spring pea rotation and the Clearfield winter wheat-spring wheat-spring pea-standard winter wheat-spring wheat-spring pea rotation (figures 3-C and 3-D) the susceptible soil seed bank was about 97.5% smaller than the original soil seed bank in year 15. Only 0.08% of the remaining total soil seed bank was herbicide-resistant in the 6-year rotation compared with 1.3% in the 3-year rotation.

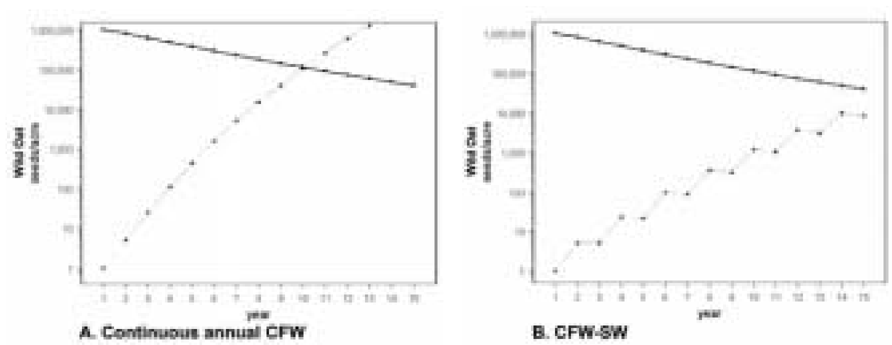
Management strategies—Low seed production and long seed dormancy are the primary reasons why the resistant soil seed bank of wild oat increased slower than the resistant soil seed bank of downy brome or jointed goatgrass. Unfortunately, these characteristics also cause the susceptible soil seed bank to decline slowly. In species with short seed dormancies, in contrast, most of the seeds produced in a single year germinate during the following growing season and the seedlings are exposed to the herbicide. Resistant biotypes are then quickly selected when herbicides with the same mode of action are applied annually. In weeds with long dormancy only a portion of the seed produced in a single year germinates during the first growing season, which results in less selection pressure.

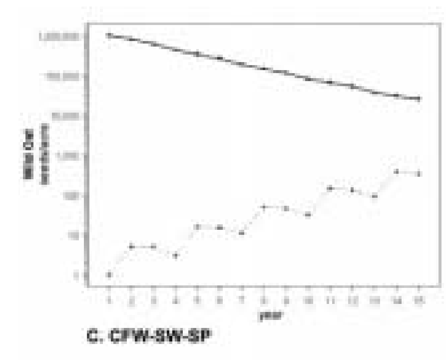
The availability of graminicides (group 1) and difenzoquat (group 8) for wild oat control during standard winter wheat and spring crop years makes longer, more diverse rotations a good management choice. However, wild oat biotypes resistant to group 1, 2, and 8 herbicides have been reported where these herbicides have been used frequently. The ability of wild oat to establish in both fall- and spring-seeded crops makes it a problem in most years of a cropping system.

The best rotation to minimize selection pressure and reduce the total wild oat soil seed bank includes both winter and spring crops and careful rotation of group 1, 2, and 8 herbicides. Use of glufosinate-resistant (Liberty Link) canola or glyphosate-resistant (Roundup Ready) canola crops in the rotation would diversify herbicide usage and reduce the potential of selecting a herbicide-resistant wild oat biotype.

Wild oat: Results of simulated rotations

Intermediate/high precipitation zone simulations





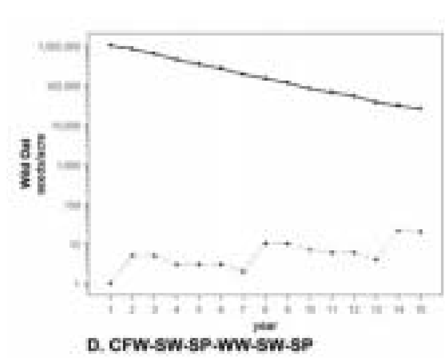


Figure 3. Wild oat seed bank under various simulated rotations: (A) continuous annual Clearfield winter wheat, (B) Clearfield winter wheat-spring wheat, (C) Clearfield winter wheat-spring wheat-spring pea, and (D) Clearfield winter wheat-spring wheat-spring pea-standard winter wheat-spring wheat-spring pea. *Note the seeds/acre axis is logarithmic.*

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.

Pesticide Residues—Any recommendations for use are based on currently available labels for each pesticide listed. If followed carefully, residues should not exceed the established tolerances. To avoid excessive residues, follow label directions carefully with respect to rate, number of applications, and minimum interval between application and reentry or harvest.

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

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