EM024

Strategies to Minimize the Risk of Herbicide-Resistant Jointed Goatgrass

Glossary

allele: form of a gene responsible for the coding of a single trait, such as herbicide resistance.

backcross: the resultant offspring from breeding a hybrid back to one of its parents.

backcross generation: the number of times the same parent is used in a cross after the initial cross. For example the BC_2 generation indicates one of the parents was crossed two additional times in that line.

biotype: naturally occurring individuals within the same species that differ in appearance and/or genetics.

gene: basic unit of inherited biological information; the portion of a strand of DNA that carries the code for a single protein or enzyme.

gene flow: movement of genes between plant populations.

genome: the complete set of DNA for an organism.

herbicide group: herbicides that act similarly on weeds; herbicides with the same fundamental biological action or site of action.

herbicide resistance: the inherited ability of a biotype to survive and reproduce following exposure to an herbicide applied at a rate that would kill the susceptible biotype.

herbicide rotation: changing the herbicide group used in a field from year to year to deploy different sites of action to minimize the potential for selection for herbicide resistance.

hybridize: crossing between varieties or species of plants to produce offspring.

Integrated Weed Management: the incorporation of all appropriate management techniques including biological, chemical, mechanical, and cultural practices in a weed control program.

mutation: random change in the genome of an organism; the result of either internal accident (a copying mistake during reproduction) or external causes such as exposure to mutagens.

natural selection: when an allele (trait) increases in a population due to pressure from the environment favoring that allele over another allele, resulting in an increase in individuals carrying the favored allele in the next generation.

nucleotide: one of the building blocks of DNA that consists of a phosphoric acid group, deoxyribose, and one of four bases: adenine (A), thymine (T), cytosine (C) or guanine (G).

out-cross: a plant that can be fertilized by another plant's pollen; the offspring resulting from cross-pollination.

plant population: a group of plants living in close proximity, under the same conditions.

selection pressure: impact of an environmental factor on the genetic composition of a population.

self-pollinating: a plant that can be fertilized by its own pollen.

semi-dominant: when a plant is heterozygous (has 1 copy of an allele) for a trait and the plant's expression of that trait is approximately half of what the expression for the trait would be when the plant is homozygous for the trait (has 2 copies of the allele).

site of action: the place in a plant where a specific herbicide works.

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Strategies to Minimize the Risk of Herbicide-Resistant Jointed Goatgrass

The purpose of this publication is to provide information about jointed goatgrass and its control with an emphasis on prevention and management of herbicide resistance. To date, herbicide-resistant jointed goatgrass acquired through natural selection has not been confirmed in the field. However, herbicide-resistant hybrids between Clearfield® wheat and jointed goatgrass have been identified in commercial wheat fields. The usefulness of Clearfield® wheat for the control of jointed goatgrass with imazamox (Beyond®) can be sustained only as long as jointed goatgrass populations remain susceptible to the herbicide.

Jointed Goatgrass Biology

- Jointed goatgrass is a winter annual grass weed with a growth habit and reproductive and vegetative characteristics very similar to winter wheat.
- Jointed goatgrass and winter wheat are closely related with a common ancestor, so they share genetic information. They have the D genome in common. Jointed goatgrass and wheat can hybridize and backcross under natural field conditions, and hybrids and backcross generations set seed. See Figure 1.
- Jointed goatgrass is predominantly self-pollinated but can cross with other jointed goatgrass plants at a low (0.4 to 2.2%) rate. The outcrossing rate in wheat is usually less than 2%.
- Jointed goatgrass plants can produce 100 to 200 seeds per plant when jointed goatgrass grows in competition with wheat. Some seeds are not dormant and germinate in the fall. However, seeds may remain dormant and viable in the soil for at least five years.
- For more information on the biology of jointed goatgrass, see EB1932: Jointed Goatgrass Ecology.

Genetic Diversity of Weeds

All of the plants living in a common area are considered a population. While plants, within a species, including weeds, may look the same, they may have a slightly different genetic makeup. Some differences in genetic makeup, or genetic diversity, are inconsequential to weed management, while others are very significant.

Plant traits, such as seed size, leaf shape, or the presence of hairs, are inherited from one generation

Figure 1. Left to right: examples of wheat, a wheat x jointed goatgrass hybrid, and jointed goatgrass. (Photo courtesy of Carol Mallory-Smith.)

to another through genes. In the simplest genetic model, two versions of a gene are present for a given trait. One version is inherited from the father (or paternal plant), and the other is inherited from the mother (or maternal plant). These versions are known as alleles.

An allele is either dominant or recessive. If it is dominant, the trait is expressed if one copy of the dominant allele is present. A recessive allele is expressed only if the offspring inherits two copies of the recessive allele—one copy from each parent.

In the context of herbicide resistance, the genetic code for an allele that normally produces an herbicide-susceptible plant can undergo a mutation and create an allele that produces an herbicide-resistant plant. Mutations in DNA are not necessarily bad; rather, mutations in general provide the variation for genetic diversity and adaptation to new environments. Herbicides do not cause the mutations for herbicide resistance in plants.

Historical Context

Herbicide-resistant crops were introduced in the USA in the early 1990s. Among the early introductions were corn hybrids that were resistant to the imidazolinone herbicide imazethapyr (Pursuit®), and cultivars of soybean that were resistant to glyphosate (Roundup®). Since that time, the number of resistant crops and herbicides they can withstand has steadily increased. Resistance to the imidazolinone herbicides has been incorporated into canola, lentils, rice, sunflower, and wheat.

Imazamox-resistant wheat, known commercially as Clearfield wheat, has been grown in the USA since 2002. Resistance to the herbicide imazamox is conferred by a semi-dominant gene. Use of this resistant wheat provides an opportunity to selectively control jointed goatgrass and other weeds in wheat with the use of imazamox on the growing wheat crop. Previously, herbicides that controlled jointed goatgrass could only be used in crop rotation or during a fallow period because they would have simultaneously damaged or killed the wheat.

Because herbicides, especially those that are similar to imazamox, are so effective at controlling weeds, they are part of the process that leads to the selection of an herbicide-resistant weed population. In a sense, the application of an herbicide creates a new environment. Only those plants that carry the mutation for resistance can survive in the new environment. This process is known as selection pressure.

Definition

Herbicide resistance is the inherited ability of a weed biotype to survive and reproduce following exposure to an herbicide at a rate that would control a susceptible biotype. Biotypes are naturally occurring plants within the same species. The difference of a single DNA nucleotide in one gene is sometimes enough to distinguish between biotypes. In the context of weed resistance, the **biotypes found in the field are commonly referred to as either resistant or susceptible.**

Selection for Herbicide-Resistant Weeds

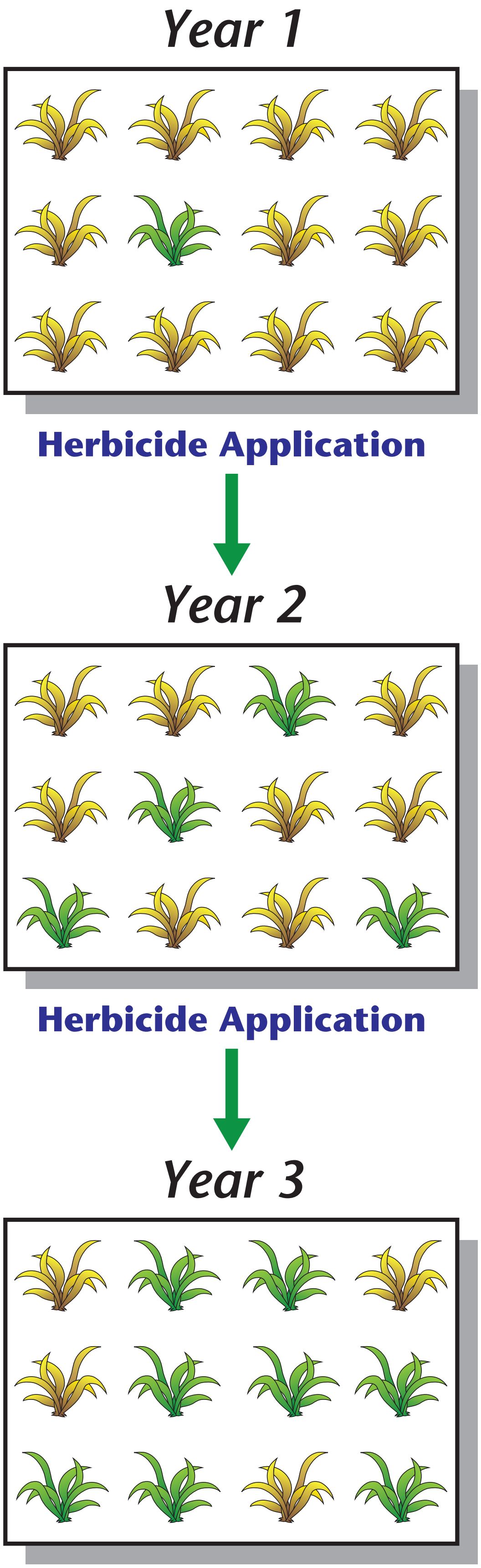
Year One. The mutation for resistance must be present in one or more plants prior to application of the herbicide. The herbicide that is associated with the resistance mutation must be applied for selection to occur. The herbicide will kill susceptible biotypes that do not have the resistance mutation and only the individuals that carry the mutant allele for resistance survive. These individuals reproduce and their seeds (carrying the resistance allele) enter the soil seed bank. The next year, there are greater numbers of resistant individuals in the population (Figure 2).

Year Two. If the herbicide that is associated with the mutation is applied again, only the individuals that are carrying the mutant allele for resistance survive. These individuals reproduce and shed seed again, thereby increasing the number of seeds with the resistance allele in the soil seed bank.

Subsequent Years. This selective survival/reproduction process repeats every year, so long as the same herbicide or herbicide group is applied, until the majority of the seed in the soil seed bank is resistant. Resistance has been shown to occur in some weed populations within five years after the first herbicide application (Year One).

Herbicide-Resistant Weeds in Wheat

A number of weed species commonly found in wheat are resistant to one or more herbicides. Herbicide-resistant biotypes of kochia, Russian thistle, prickly lettuce, Italian ryegrass, wild oat, downy brome, pigweed, mayweed chamomile, common lambsquarters, and other weed species have been confirmed throughout the wheat-growing regions of the USA. These examples illustrate that a wide variety of weeds are vulnerable to selection for herbicide-resistant biotypes.



Prevention and Management

Herbicide resistance is a major issue affecting wheat production in the United States. An Integrated Weed Management program is the best approach for the prevention and management of herbicide resistance and for maximum protection of future management options. A brief summary of management practices and their influence on the selection of imazamox-resistant jointed goatgrass is presented in Table 1. Some management practices are related to herbicide use, while others are a function of environment and cultural practices. Management practices that reduce the competitiveness of jointed goatgrass also mitigate some of the risk of selecting for herbicide resistance. For more information on jointed goatgrass management techniques, see WSU Extension bulletins at http://jointedgoatgrass.wsu.edu/jointedgoatgrass/bulletins/index.htm.

Scouting. Scouting is an important, but often overlooked, part of weed management. Fields should be scouted both before and after herbicide applications. Scouting is the only way to document which weeds are present, what their densities are at the time of application, and how they responded to herbicide applications.

Accurate Record Keeping. Records should document the use of herbicides and herbicide groups, including the rates and application timings. Application notes and/or maps should also contain follow-up observations of which weed species were present in a given field before application and how well the particular herbicide(s) controlled them.

Using Herbicides to Delay Resistance

In 1997, herbicides were classified by site of action (their fundamental biological action) into groups for the specific purpose of addressing herbicide resistance (Table 2). A commercial herbicide may belong to more than one group if it is a mixture of herbicides. Herbicide groups are described in greater detail in the Weed Science Society of America's Herbicide Handbook, and in Extension bulletins.

Successful management to prevent the selection of imazamox-resistant jointed goatgrass requires the use of herbicides from different herbicide

Figure 2. (at left) Diagram showing the increase in herbicide resistant weeds in a population over time due to selection by repeated application of the same herbicide or herbicides with the same site of action (Group). (Yellow = Susceptible plant; Green = Resistant plant) (Illustration courtesy of Michael Quinn, Oregon State University.)

Table 1. A Summary of Weed Management Practices in Wheat and their Influence on the Selection of Imazamox-Resistant Jointed Goatgrass

Practice	Influence on Selection Pressure	Influence on Gene Flow
Clearfield wheat, sprayed with a Group 2* herbicide	increase	increase
Clearfield wheat, not sprayed with a Group 2 herbicide	neutral	increase
Crop rotation	decrease	decrease
Herbicide rotation	decrease	decrease
Lack of non-chemical jointed goatgrass control measures	increase	increase
Tank mix of herbicides with different modes of action	decrease	neutral
Tillage for weed control	decrease	decrease
Uncontrolled jointed goatgrass at planting	increase	increase
Uncontrolled jointed goatgrass at harvest	increase	increase
Use of full labeled herbicide rates	decrease	decrease
Use of reduced rates	increase	increase
Use of split applications	increase	increase
Presence of volunteer herbicide-resistant wheat plants	neutral	increase

**"Group" relates to site of action of the herbicide (Table 2).*

groups. The limited number of herbicides available for use in wheat, and especially for controlling jointed goatgrass, makes it even more important to understand herbicide groups and make the best use of the limited choices.

Rotate Herbicide Groups. Crop rotation creates opportunities for herbicide rotation. Some common wheat rotations and typical use patterns for the USA are described in Table 3.

In a traditional winter wheat–fallow rotation, 2,4-D, dicamba, or MCPA may be applied in-season for control of broadleaf weeds. These herbicides are known as Synthetic Auxins (their family name) and belong to Group 4.

If Clearfield wheat was planted, imazamox may be applied in-season. Imazamox is one of several ALS-inhibiting herbicides, known collectively as Group 2. Some Group 2 herbicides (sulfonylureas, imidazolinones, and others) are used to control broadleaf weeds in wheat without the use of Clearfield wheat. Resistance to Group 2 herbicides has been the most widespread, compared to resistance in all other herbicide groups.

As of 2008, Beyond herbicide was the only labeled and approved herbicide for selective control of jointed goatgrass in Clearfield wheat. This herbicide contains imazamox, an herbicide in the Group 2 family. Growers who plant Clearfield wheat should consider limiting their use of imazamox and other Group 2 herbicides to no more than twice in any six-year period.

During the fallow season, a non-selective herbicide may be used for control of broadleaf and grass weeds. The most common non-selective herbicide is glyphosate (Group 9). Paraquat (Group 22) may also be used. In summary, few options exist to rotate among groups in a winter wheat–fallow rotation for jointed-goatgrass.

Use of Herbicide Mixtures. Herbicide mixtures are part of an effective resistance management plan. Simply mixing, however, without proper consideration of herbicide activity, is not effective. Mixing may actually increase the likelihood of selecting for resistance.

The general goal of herbicide mixtures is to add another product in the tank (herbicide #2) to control a weed species that is not controlled by the primary herbicide (#1). To be effective in the prevention and management of herbicide resistance, however, the herbicide mixture must have the same effect in the field. In other words, each herbicide in an herbicide mixture must be effective on the same weed, have the same application timing, have the same soil activity, and yet come from a different group. **Only when a weed is treated with herbicides from different groups is the selection pressure for resistance reduced.**

Use of Clearfield Wheat. Selective control of jointed goatgrass in winter wheat is possible using

Table 2. Herbicide groups for herbicides commonly used in wheat production systems.*

Group Number	Site of action	Example(s)
Group 1	Acetyl CoA carboxylase (ACCase) inhibitors	clethodim (Select); sethoxydim (Poast); tralkoxydim (Achieve); clodinofop (Discover); pinoxaden (Axial)
Group 2	Acetolactate synthase (ALS) inhibitors	imazamox (Beyond); mesosulfuron (Osprey); metsulfuron (Ally); sulfosulfuron (Maverick); thifensulfuron methyl (Harmony Extra)
Group 3	Microtubule assembly inhibitors	pendimethalin (Prowl); trifluralin (Treflan)
Group 4	Synthetic auxins	dicamba (Banvel, Clarity); fluroxypyr (Starane)
Group 5	Photosystem II inhibitors	atrazine (Aatrex); metribuzin; bromacil (Hyvar)
Group 6	Photosystem II inhibitors	bentazon (Basagran); bromoxynil (Buctril)
Group 9	EPSP** synthase inhibitors	glyphosate (Roundup, Touchdown)
Group 14	Inhibitors of protoporphyrinogen oxidase (Protox)	oxyflurofen (Goal); flumioxazin (Valor); carfentrazone (Aim); sulfentrazone (Spartan)
Group 15	Inhibitors of very long chain fatty acid synthesis	alachlor (Lasso); dimethanamid-(p) (Outlook); metolachlor (Dual); flufenacet (Define)
Group 22	Bipyridiliums	paraquat (Gramoxone)
Group 27	Inhibitors of HPPD***	pyrasulfotole (Huskie); includes bromoxynil

** Products may not be registered for use on wheat but on fallow or other crops grown in common wheat rotations.*
*** 5-enolpyruvylshikimate-3-phosphate*
**** 4-hydroxyphenyl-pyruvate-dioxygenase*

imidazolinone-resistant wheat. Specific wheat varieties, distinguished from other varieties by the trade name Clearfield, withstand labeled rates of imazamox post-emergence. The use of these herbicides in wheat to control jointed goatgrass is a practice that should be managed to prevent resistance in the jointed goatgrass. Consult the label on Beyond for application instructions.

Other forms of herbicide-resistant wheat may be available in the future. Specific management plans related to these forms and the control of jointed goatgrass will need to be published then. However, many of the fundamentals of herbicide resistance and strategies for prevention and management of herbicide-resistant weeds are consistent from one cropping system and/or problem weed to another. The fundamental principle behind prevention and management of herbicide resistance remains: minimize or eliminate the selection pressure on the weed or weeds.

Delaying Resistance through Non-Chemical Means

Herbicide rotation alone is not sufficient to lower the risk of selecting for herbicide-resistant jointed goatgrass. Non-chemical control measures, such as use of certified/clean seed, crop rotation, increased seeding rates, narrow row spacing, fertilizer placement within the row, and planting competitive varieties, also mitigate the risk of selecting imazamox-resistant jointed goatgrass. These cultural control methods reduce the spread and competitiveness of jointed goatgrass while contributing to a reduced likelihood of selecting for herbicide-resistant biotypes.

Plant Clean Seed. Planting seed that contains no jointed goatgrass seed will prevent the introduction of jointed goatgrass in jointed goatgrass-free fields and will not futher increase populations in fields that have infestations of jointed goatgrass. Certified seed has passed field inspection and meets seed testing standards for varietal purity based on the standards of state certification boards. Current certification standards in the Pacific Northwest specify zero tolerance of jointed goatgrass and hybrid plants at inspection of certified seed fields. Clearfield wheat seed must be certified and may not be saved by growers to plant in subsequent years. Other states may allow a small percentage of jointed goatgrass in their seed.

Table 3. Some Common Wheat Rotations and Typical Herbicide-use Patterns for the USA

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 for broadleaf weeds
Summer fallow	Any time in the summer—Group 4 and 9 for broadleaf and grass weeds	
Herbicide Groups Used: 2, 4, and 9		

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 and 27 for broadleaf weeds
Spring wheat	None	Group 1 and 2 for grass weeds Group 2, 4, and 27 for broadleaf weeds
Summer fallow	Any time in the summer—Group 4, 9, and 27 for broadleaf and grass weeds	
Herbicide Groups Used: 1, 2, 4, 9, and 27		

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 and 27 for broadleaf weeds
Spring wheat	None	Group 1 and 2 for grass weeds Group 2, 4, and 27 for broadleaf weeds
Summer fallow	Group 2 for broadleaf and grass weeds Group 3 for grass and broadleaf weeds Group 5 for broadleaf weeds	Group 4 or 5 for broadleaf weeds Group 1 for grass weeds Group 27 for broadleaf weeds
Herbicide Groups Used: 1, 2, 3, 4, 5, and 27		

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 and 27 for broadleaf weeds
Spring barley	Group 9 for broadleaf and grass weeds	Group 2, 4, 6, and 27 for broadleaf weeds
Herbicide Groups Used: 2, 4, 6, 9, and 27		

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 for broadleaf weeds
Safflower	Group 3, 9, or 15 for broadleaf and grass weeds	Group 1 for grass weeds
Summer fallow	Any time in the summer—Group 4, 9, and 27 for broadleaf and grass weeds	
Herbicide Groups Used: 1, 2, 3, 4, 9, 15, and 27		

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 for broadleaf weeds
Proso millet	None	Group 14 for broadleaf weeds
Summer fallow	Any time in the summer—Group 4, 9, and 27 for broadleaf and grass weeds	
Herbicide Groups Used: 2, 4, 9, 14, and 27		

Table 3 (continued). Some Common Wheat Rotations and Typical Herbicide-use Patterns for the USA.

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 for broadleaf weeds
Sunflower	Group 3 for small seeded grass and broadleaf weeds	Group 14 for broadleaf weeds
Summer fallow	Any time in the summer—Group 4 and 9 for broadleaf grass weeds	
Herbicide Groups Used: 2, 4, 9, and 14		

Crop Rotation	Preplant or Preemergence Herbicides	Postemergence Herbicides
Winter wheat	None	Group 2 for broadleaf and grass weeds Group 4 for broadleaf weeds
Corn	None	Group 9* and 27 for broadleaf and grass weeds
Summer fallow	Any time in the summer—Group 4 and 9 for broadleaf grass weeds	
Herbicide Groups Used: 2, 4, 9 (resistant to glyphosate), 14, and 27*		

No matter the seed source, fields should be scouted for jointed goatgrass and hybrids due to germination of jointed goatgrass and hybrid plants from the soil seed bank.

Crop Rotation. Crop rotation is an effective management strategy for the control of jointed goatgrass and minimizes the risk of selecting for herbicide-resistant weeds. The best practice for crop rotation is to use two or more crops in rotation and rotate to a different crop every year.

In most cases, herbicide rotation accompanies crop rotation. However, the popularity of herbicide-resistant crops that are resistant to the same herbicide group creates challenges for crop rotation and control of herbicide-resistant volunteer plants. Rotation within a group of herbicide-resistant crops may lead to an increased risk of selecting herbicide-resistant weeds.

Wheat crop rotations vary considerably across the United States, within production regions, and from grower to grower. Several crop and herbicide rotations common in the USA are listed in Table 3.

Plant-back restrictions for Beyond are updated as new data and varieties become available. Because plant-back restrictions vary down to the county level, a local extension agent, agronomist, seed

Figure 3. An unmanaged stand of jointed goatgrass between a field road and a stand of wheat. (Photo courtesy of Carol Mallory-Smith.)

dealer, or company representative will have the most accurate information. Read and follow label instructions.

Additional benefits of crop rotation include opportunities for changes in cultural practices such as planting, harvest dates, and fertility programs, which lead to better soil and crop health. Also, crop rotation may allow for tillage and can prevent some weeds from becoming the predominant species. Crop rotation may break the life cycles of insects and pathogens and lead to improved yields.

Manage the Entire Field. Whatever the control techniques, be thorough in controlling jointed goatgrass. If spraying, the entire field should receive an application at a rate that is high enough to control jointed goatgrass. Jointed goatgrass adjacent to fields—in ditches and along fence lines and gates—should be controlled (Figure 3). Mowing, burning, or a non-selective herbicide can be used where applicable. Jointed goatgrass plants that are left uncontrolled may be pollinated by wheat and contribute to gene flow, thereby increasing the risk of herbicide-resistant jointed goatgrass biotypes.

Herbicide Resistance due to Gene Flow

Movement of the herbicide-resistance gene from Clearfield wheat to jointed goatgrass has been documented in commercial production fields. This movement of genetic material, known as gene flow, is another path for the evolution of imazamox resistance in jointed goatgrass. Gene flow can be minimized, however, through good crop management.

The key to reducing the risk of gene flow is to prevent the presence of herbicide-resistant hybrid plants in the field and thereby eliminate the potential for production of backcross generations. If backcross generations do not form, gene flow does not occur. For specific details of reproduction between wheat and jointed goatgrass, see WSU Extension Bulletin EB1934, Jointed Goatgrass Genetics.

Production practices that decrease the potential for hybrids to occur in the field include using certified/clean seed, and/or not replanting seed harvested from fields infested with jointed goatgrass, and using crop rotation. Both practices prevent the introduction of hybrids between wheat and jointed goatgrass into a field and prevent production of the first backcross generation.

Hybrid seed already present in the field may produce volunteer plants. These hybrids are usually taller than the surrounding wheat crop (Figure 4). Because they occur at generally low frequencies, hand-pulling these plants is an efficient method to reduce the risk of gene flow. The presence of hybrids also serves as an indicator of the presence of jointed goatgrass in the field, so steps should be taken to reduce the spread of jointed goatgrass to adjacent fields especially during harvest.

Control of Herbicide-Resistant Volunteer Plants. The presence of herbicide-resistant volunteer wheat plants in subsequent crops can lead to an increased risk for gene flow. Volunteer wheat is generally considered a problem within one year of harvest. The use of herbicides and tillage between plantings,

Figure 4. Mature hybrid plants in the field are often taller than the surrounding wheat crop. (Photo courtesy of Carol Mallory-Smith.)

during the fallow period, and within other crops are effective at controlling volunteer wheat plants.

How to Recognize Resistance in the Field

Irregular patches of a single weed species in the field are an indication of herbicide resistance, especially when—

- There are no obvious problems with the herbicide application, including weather.
- There are no or minimal herbicide symptoms on the weed species that is suspected of being resistant.
- Other weed species listed on the label are controlled.
- There has been a previous failure to control the same species in the same field with the same herbicide or herbicide group.
- Records show repeated use of one herbicide or of herbicides in the same group.

If You Suspect Resistance in the Field

Do not re-spray the field with the same herbicide. Report your suspicion to University Research or Extension personnel or to the Extension educator in your county. You will be provided with instructions for collecting plants or seed that can be used to test for herbicide resistance.

Summary

The potential for the selection of imazamox-resistant jointed goatgrass is high due to characteristics of the Group 2 herbicides and the ability for gene flow between wheat and jointed goatgrass. Several strategies aimed at the prevention of, and management to delay, resistance are available. Herbicides and herbicide-resistant wheat are components of an herbicide-resistance management strategy, and rotation among herbicide groups is necessary. Scouting and accurate record keeping are the best management practices to detect the shift from susceptible to resistant biotypes. Non-chemical control measures that reduce the competitiveness of jointed goatgrass, such as crop rotation, increased seeding rates, narrow row spacing, fertilizer placement within the row, and planting competitive varieties, also mitigate the risk of selecting imazamox-resistant jointed goatgrass.

References

Anderson, R., E. Zakarison, D. Ball, G. Wicks, D. Lyon, W. Donald, S. Miller, F. Young, and T. White. 2002. *Ecology of Jointed Goatgrass*. EB1932. Washington State University Extension.

Campbell, J., C. Mallory-Smith, A. Hulting, and D. Thill. 2011. *Herbicide-Resistant Weeds and Their Management*. PNW 437. University of Idaho Extension.

Hanavan, D., T. White, E. Zakarison, and R. Anderson. 2004. *Introduction to Jointed Goatgrass*. EB1931. Washington State University Extension.

Mallory-Smith, C. and E. Retzinger. 2003. Revised Classification of Herbicides by Site of Action for Weed Resistance Management Strategies. *Weed Tech*. 17:605-619.

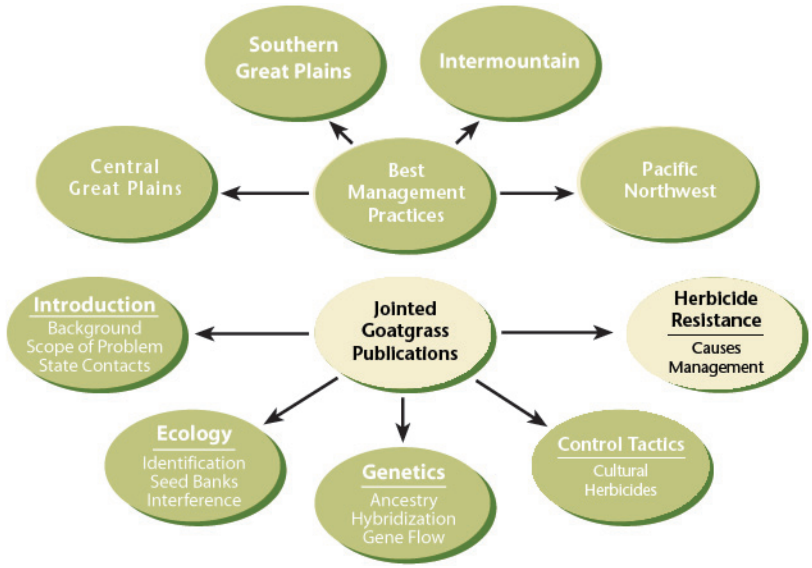
Quinn, M., D. Morishita, J. Evans, R. Whitesides, and T. White. 2007. *Jointed Goatgrass, Best Management Practices, Intermountain Region*. EB2003. Washington State University Extension.

Schmale, D., R. Anderson, D. Lyon, and B. Klein. 2008. *Jointed Goatgrass, Best Management Practices, Central Great Plains*. EB2033E. Washington State University Extension.

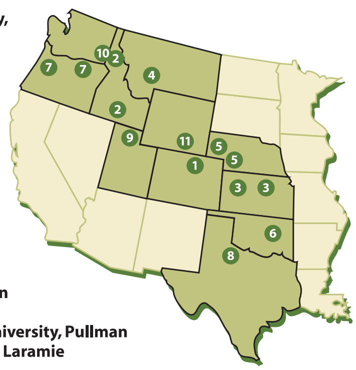
Wicks, G., R. Anderson, T. White, P. Stahlman, and D. Morishita. 2005. *Jointed Goatgrass Control Tactics*. EB1935. Washington State University Extension.

Yenish, J., D. Ball, and R. Schirman. 2009. *Integrated Management of Jointed Goatgrass in the Pacific Northwest*. EB2042. Washington State University Extension.

Zemetra, R., C. Mallory-Smith, and T. White. 2006. *Jointed Goatgrass Genetics*. EB1934. Washington State University Extension.



1–Colorado—Colorado State University, Ft. Collins
2–Idaho—University of Idaho, Moscow & Twin Falls
3–Kansas—Kansas State University, Hays & Manhattan
4–Montana—Montana State University, Bozeman
5–Nebraska—University of Nebraska, North Platte & Scottsbluff
6–Oklahoma—Oklahoma State University, Stillwater
7–Oregon—Oregon State University, Corvallis & Pendleton
8–Texas—Texas A&M University, Vernon
9–Utah—Utah State University, Logan
10–Washington—Washington State University, Pullman
11–Wyoming—University of Wyoming, Laramie



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EXTENSION

Use pesticides with care. Apply them only to plants, animals, or sites as listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

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