JOINTED GOATGRASS: BEST MANAGEMENT PRACTICES CENTRAL GREAT PLAINS

Abstract

Jointed goatgrass is a winter annual grass weed that competes with wheat, resulting in reduced yield and increased grain dockage. Managing jointed goatgrass in winter wheat requires a systems approach that integrates multiple control tactics, described in this bulletin. Control tactics include prevention of seed entry into fields, use of herbicides, seed bank management, improved planting techniques, and crop rotations. Integration of multiple control tactics is the key to effective management of jointed goatgrass. The practices described in this bulletin are intended for dryland wheat producers in the western part of the Central Great Plains. This includes producers in areas of western Kansas, eastern Colorado, western and southern Nebraska, and southeastern Wyoming.

Introduction

Jointed goatgrass (*Aegilops cylindrica* Host) is an invasive winter annual grass that causes serious problems in winter wheat in the western United States. Jointed goatgrass reduces wheat yield by competing with wheat for sunlight, soil moisture, and soil nutrients. It is an especially good competitor under conditions of stress such as drought. Research has shown that winter wheat infested with as few as 18 jointed goatgrass plants per square yard can cause a yield reduction of nearly 30%. If not controlled, jointed goatgrass will eventually choke out wheat, reducing wheat yields to zero in parts of the field. The emergence and growth patterns of jointed goatgrass and winter wheat are generally similar. Both species germinate together and seedlings can emerge from the same soil depths. However, jointed goatgrass is comparatively more winter hardy than winter wheat. Jointed goatgrass seeds generally mature before or with winter wheat in the Central Great Plains.

In addition to yield losses, wheat grains contaminated with jointed goatgrass will be discounted for dockage when it is delivered to an elevator. Typical discounts are 4¢/bushel at 1% dockage, 11¢/bushel at 2% dockage, and 18¢/bushel at 3% dockage.

This bulletin will help wheat producers avoid such economic losses by providing information on Best Management Practices for the control of jointed goatgrass in winter wheat. The practices described in this bulletin are intended for dryland wheat producers in the western part of the Central Great Plains. This includes producers in areas of western Kansas, eastern Colorado, western and southwestern Nebraska, and southeastern Wyoming, where the predominant dryland cropping systems are winter wheat–fallow, or winter wheat–spring planted crop–fallow.

DOLLAR LOSSES FROM FAILURE TO CONTROL JOINTED GOATGRASS CAN BE SEVERE!

EXAMPLE: A producer delivers a 1000 bushel load of wheat that contains 3% dockage from jointed goatgrass. If grain from a field contains 3% jointed goatgrass, it is reasonable to assume that the field suffered a 15% yield loss as a result of the jointed goatgrass infestation. At a wheat price of $4.00 per bushel, with the dockage discounts listed above, this producer lost $180.00 from dockage discounts (1000bu x $0.18/bu) and $600.00 from lost production (1000bu x 15% yield loss x $4.00/bu). Jointed goatgrass cost this producer over $750.00 on just one truckload. If the producer harvested 20,000 bushels of similar wheat, total losses would be over $15,000. At higher wheat prices the losses will be even greater.

WASHINGTON STATE UNIVERSITY EXTENSION

Introduction to a Multi-Practice Approach For Jointed Goatgrass Management

Wheat producers have many control practices to choose from when managing jointed goatgrass. However, seldom will a single practice provide acceptable control, especially over a number of years. Effectiveness varies because of such things as drastic differences in weather and differing levels of jointed goatgrass emergence between years. To successfully control jointed goatgrass and other problem weeds, producers should use a **multi-practice** approach in which a producer combines a number of management practices to achieve better weed control than could be obtained by relying on only one or two practices.

Figure 1. Blade (flat part of leaf), ligule (thin appendage between blade and sheath), and sheath (base of leaf that encloses the stem) of a grass plant. Note: the grass plant shown is downy brome, which has soft dense hairs covering the sheath and leaf blade.

A checklist of possible practices is provided below to show producers numerous options that are available for the control of jointed goatgrass. Often, these same practices can also be used to control other grass weeds such as downy brome and volunteer rye. Since many management practices are most appropriate at a specific time during the year, this bulletin discusses them in a timeline arrangement. This timeline begins at wheat harvest, the point at which many producers first notice a jointed goatgrass infestation, and progresses through the cropping cycle. Producers should review the entire sequence, however, as successful use of a given practice may depend on the use of other practices earlier or later in the cropping cycle.

Identification and Biology

Jointed goatgrass management begins with correct plant identification. Winter wheat (*Triticum aestivum* L.), jointed goatgrass, and downy brome (*Bromus tectorum* L.) are all winter annual grasses that often grow side-by-side.

Figure 1 identifies the blade, ligule, and sheath of a grass plant. Jointed goatgrass seedlings look very similar to wheat seedlings, except jointed goatgrass leaves have visible hairs growing along the edge of the leaf (Figure 2). Wheat leaves are generally hairless. If hairs do appear on wheat leaves, they will be sparse, as well as longer and more randomly spaced than hairs on jointed goatgrass

Figure 2. Wheat on left, jointed goatgrass on right. Wheat leaves are generally hairless. If hairs do appear on wheat leaves they will be sparse, longer, and more randomly spaced than hairs on jointed goatgrass leaves.

Figure 3. Jointed goatgrass seedling with attached spikelet (joint).

leaves. The sheath on wheat is hairless. In contrast, the sheath and leaf blade on downy brome are covered with soft dense hairs (Figure 1). To positively identify jointed goatgrass in the early seedling stage, dig up a plant and look for a spikelet (joint) attached to the root (Figure 3).

Jointed goatgrass may also be growing alongside volunteer rye (*Secale cereale* L.), another winter annual grass that is a problem weed in winter wheat. (Volunteer rye is also known as feral rye, common rye, or cereal rye.) It is very difficult to distinguish volunteer rye seedlings from winter wheat seedlings. Volunteer rye seedlings may be a darker green color, or the leaves may be slightly wider. To positively identify volunteer rye, dig up a plant and look at the seed.

As jointed goatgrass begins to head, it is easy to distinguish from wheat, downy brome, or volunteer rye. The head of jointed goatgrass, also called the spike, is a long narrow cylinder. This spike is made up of a number of spikelets, also called joints (Figure 4). Each spikelet or "joint" is about one-half-inch long and contains from one to three seeds. At maturity, which normally occurs two to three weeks before wheat is harvested, part of the jointed goatgrass spike will often break off and the spikelets will fall to the ground. Spikelets that remain attached to the jointed goatgrass stem, and that are harvested with the wheat, will look like short pieces of straw when mixed with wheat in the combine bin. Wheat straw is hollow, however, while jointed goatgrass spikelets (joints) are closed on both ends.

Occasionally, wheat and jointed goatgrass will cross and produce a hybrid plant. When mature, this hybrid will share the appearance of both the parent plants (Figure 5). Hybrids were thought to be sterile until recent studies confirmed that 1 to 2% of the seeds on hybrid plants are viable.

Figure 4. Jointed goatgrass head (spike), and head separated to show individual spikelets (joints).

Figure 5. Left to right: wheat, wheat x jointed goatgrass hybrids (3 hybrids shown), and jointed goatgrass.

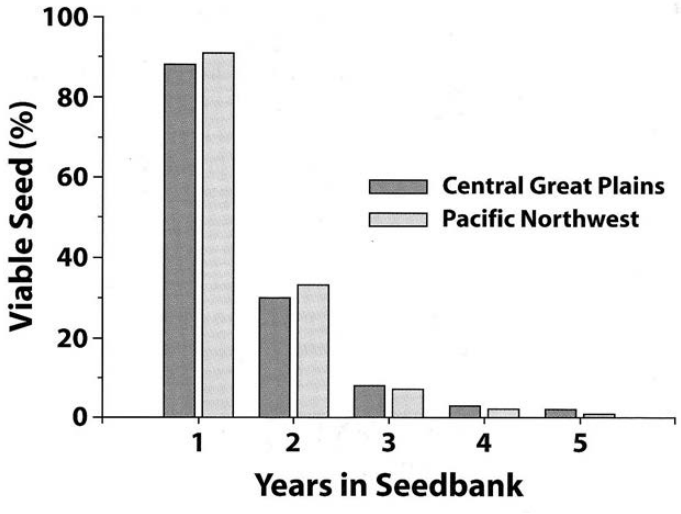


Figure 6. Longevity of seeds of jointed goatgrass in soil. Research conducted at sites in the Central Great Plains and Pacific Northwest, where rainfall ranged from 15 to 18 inches per year.

A key to managing jointed goatgrass is understanding the survival of jointed goatgrass seeds in the soil. After one year, 80% or more of jointed goatgrass seeds may still be viable. After two years, 20% may be viable, and after three years, 5% may be viable (Figure 6). This is in sharp contrast to downy brome, which may have less than 20% seed viability after one year.

Seed survival is a major reason that jointed goatgrass is difficult to control in wheat-fallow rotations. Because 20% or more of jointed goatgrass seed can survive two years or longer, even after a year of fallow there may be a significant amount of viable jointed goatgrass seed in the soil. This reservoir of viable weed seed is called the **soil seed bank**. Some of this seed then germinates and establishes new jointed goatgrass plants in the next wheat crop. These new plants produce even more seed, further infesting future wheat crops.

As part of this multi-year seed survival, jointed goatgrass has a characteristic of staggered seed dormancy. Each jointed goatgrass spikelet contains from one to three seeds and, even under optimum conditions, not all seeds within a spikelet may germinate at one time. This dormancy will spread germination over several years, making jointed goatgrass difficult to control in wheat–fallow rotations.

Jointed goatgrass can germinate on the soil surface, or it can emerge from as deep as 4 inches in the soil. In comparison, downy brome will rarely emerge from depths greater than 2.5 inches. Shallow tillage to incorporate jointed goatgrass spikelets into the soil may stimulate germination, but the results vary. Again, this is in contrast to downy brome where even a small amount of seed-soil contact will greatly increase germination.

Typically, jointed goatgrass emerges in the fall, vernalizes during winter, and heads out to produce seed in the spring. However, jointed goatgrass plants that emerge in the early spring can also produce seed heads that may contain viable seed. Jointed goatgrass generally heads after downy brome, but before wheat.

One other difference between jointed goatgrass and wheat is that anthesis (the period during which flowers in the emerged head are pollinated and become viable seeds) is much longer for jointed goatgrass than for winter wheat. Anthesis in both plants is identifed when anthers (small, yellow cylinders of pollen) are visible on the heads. A long anthesis gives jointed goatgrass a better opportunity for favorable weather during anthesis and helps ensure seed production.

Another concern for producers is the ability of jointed goatgrass to produce viable seeds shortly after heading. The first heads to emerge on a jointed goatgrass plant may produce viable seeds before other heads on the same plant have even emerged. This means control of jointed goatgrass plants must be accomplished in a timely manner to prevent production of new seed.

Producers should remember that one jointed goatgrass plant can produce dozens of seeds, leading to many more jointed goatgrass plants in the next wheat crop. Jointed goatgrass populations and wheat yield losses from these populations can quickly become severe.

Further information on jointed goatgrass identification and biology can be found in the bulletin "Jointed Goatgrass Ecology" (Washington State University EB1932) available at *www.jointedgoatgrass.wsu.edu* or from university extension specialists.

Management at Wheat Harvest

Management practices to control jointed goatgrass by preventing the spread of seeds should begin at wheat harvest. During harvest, watch for and note wheat fields that contain jointed goatgrass, including patches of jointed goatgrass bordering clean fields. Pay particular attention to areas where water drainage from adjoining fields may have deposited jointed goatgrass seed during runoff. If GPS is available on the combine, infestation maps of jointed goatgrass can aid in its further management.

Also during harvest, note whether the jointed goatgrass infestation in a field is a critical population or a background population. A **critical population** is one in which jointed goatgrass is so dense, and accumulated jointed goatgrass seed in the soil seed bank is so high, that yield of the next wheat crop will be severely reduced unless major corrective action is taken. A **background population** is one in which the level of jointed goatgrass is low and has been low for several years. Therefore, the accumulated jointed goatgrass seed in the soil seed bank is not great enough to cause a significant reduction in yield of the next wheat crop. Without proper management, background populations of jointed goatgrass can quickly become critical populations, especially in a winter wheat–fallow rotation.

During wheat harvest producers should: 1) tarp trucks to prevent spikelets from blowing off loads and infesting the edges of other fields; 2) abandon or cut infested backswaths last in fields that are otherwise uninfested; 3) harvest fields with high jointed goatgrass infestations last, especially if the field has a critical population; 4) thoroughly clean combines after they have harvested a field or backswaths that contain jointed goatgrass.

Typically, 50% or more of jointed goatgrass spikelets (joints) break off and fall to the ground before wheat is harvested. Therefore, it is unlikely that adjusting the combine to try and save remaining spikelets to the bin will significantly reduce additions of jointed goatgrass seed to the soil seed bank. Instead, set the combine to minimize dockage and maintain grain quality.

Adjust and maintain straw and chaff spreaders to distribute threshed straw and chaff uniformly over as much of the header width as possible. Jointed goatgrass and other grass weed seedlings that emerge in dense bands, partially covered with heavy amounts of straw or chaff, are difficult to control with either herbicides or tillage.

Figure 7. Poor chaff and straw distribution and harvest started in same area for each crop.

Not spreading the crop residue evenly the width of the header and also starting harvest in the same area of the field will result in areas with higher and lower soil organic matter. See Figure 7.

Adjust cutting height to match future plans for a field. If moldboard plowing will be the first weed control operation in the spring, shorter stubble will allow the plow to better invert the furrow slice and bury jointed goatgrass spikelets deep enough to prevent seedling emergence. Taller stubble will provide a better environment for post-harvest or spring weed control with glyphosate herbicide. (Glyphosate is the common name for the active ingredient in numerous products such as Roundup®, Buccaneer®, Gly Star™, etc.) Taller stubble will also provide better moisture savings in stubblemulch or chemical fallow, or for planting of a no-till spring crop.

Producers may be concerned that if they cut wheat high in order to leave tall stubble, that remaining sucker heads are leaving too much grain in the field. If the actual amount of grain left with a few low heads is calculated, it can be shown that the losses are minor. Since most very low heads are small and contain light grain, 50 low heads in a 10-by-10-foot area may produce less than 1/3 bushel per acre. Also, the light grain in small, low heads can reduce the test weight of grain for the entire field, causing price discounts. With the fuel and time savings at harvest from not running extra material through the combine, and with the increased success and yield of no-till spring crops in taller stubble, it is unlikely that cutting low is cost effective unless moldboard plowing is planned.

Using Harvest Weed Seed Control

Jointed goatgrass plants retain a significant amount of seed in the spikes (heads) at the time of wheat harvest. Impact mill systems installed in combines can render seed in the chaff stream nonviable before the chaff and seed is spread behind the combine. Another harvest weed seed

control method available for managing jointed goatgrass is chaff lining, which buries weed seeds in a thick layer of wheat chaff at the time of wheat harvest. A study looking at the effect of wheat chaff lining on predominant grass weed species has recently been initiated in the Central Great Plains.

Management in Stubble Between Harvest and Fall Freeze-Up

The evaluations at wheat harvest, noting whether fields infested with jointed goatgrass have critical populations or background populations, should now be used to plan future management.

Again, fields with a critical population of jointed goatgrass are those in which jointed goatgrass is so dense, and accumulated jointed goatgrass seed in the soil seed bank is so high, that yield of the next wheat crop will be severely reduced unless major corrective action is taken. Fields with a background population of jointed goatgrass are those in which the level of jointed goatgrass is low, and has been low for several years. Therefore, the accumulated jointed goatgrass seed in the soil seed bank is not great enough to cause a significant reduction in yield of the next wheat crop.

For fields with a critical population of jointed goatgrass, major corrective action will be required before another wheat crop can successfully be grown. This will involve the use of one or more intensive reclamation practices.

Combining reclamation practices will increase success. The intensive reclamation practices are:

1) rotation to a late spring-planted crop for at least two consecutive years

2) one-time moldboard plowing

3) use of Clearfield™ wheat, which allows in-crop application of an imazamox herbicide such as Beyond™

4) use of CoAXium™ wheat production system, which allows in crop application of quizalofop-p-ethyl (Aggressor™ herbicide)

Rotation to a late spring-planted crop for at least two consecutive years is the best intensive reclamation practice to use if a producer can profitably grow a rotational crop. While the other intensive reclamation practices have also been shown to eliminate or significantly reduce critical populations of jointed goatgrass, environmental conditions such as drought may reduce their effectiveness in some years. The multi-year aspect of crop rotation increases its success.

Crop rotation also allows the additional use of one or more of the other intensive reclamation practices if there are concerns that reclamation was not complete.

It is important to use a late spring-planted crop to avoid seed production from jointed goatgrass that emerges in the early spring. Possible crops and rotations include: proso millet–proso millet; corn–proso millet; grain sorghum–proso millet; corn–sunflower; or grain sorghum–sunflower. Producer experience, location, and individual circumstance will determine other possible rotations. A minimum of two years of a late spring-planted crop, plus one year of fallow, are required before again planting wheat into a field that is being reclaimed from a critical population of jointed goatgrass. The long seed life and the seed dormancy of jointed goatgrass make shorter rotations ineffective for depleting large amounts of jointed goatgrass seed from the soil seed bank. If producers only use one year of a late spring-planted crop, they should plan on moldboard plowing in the subsequent fallow year and/or using Clearfield™ or CoAXium™ wheat for the subsequent wheat crop. Early spring-planted crops such as oats or spring barley should not be used as rotational crops because jointed goatgrass may emerge and produce viable seed in those crops.

Conserving moisture by controlling weeds and volunteer wheat after harvest is a key step in preparing to grow a late spring planted crop. Even low water-use spring crops such as proso millet will benefit from moisture captured and stored after wheat harvest. Post-harvest weed control will be easier if broadleaf weeds were controlled in the previous wheat crop. Herbicide use for post-harvest weed and volunteer wheat control is almost always preferred to tillage: avoiding tillage between harvest and fall freeze-up enhances moisture capture and storage by preserving residue cover and soil structure. (For details on post-harvest weed control with herbicide, see Appendix A.)

Producers who have fields with a critical population of jointed goatgrass, but who cannot rotate to a late spring-planted crop for at least two consecutive years, should plan to use one or more of the remaining intensive reclamation practices: moldboard plowing and/or the use of Clearfield™ or CoAXium™ wheat. The effectiveness of these practices will also be enhanced by post-harvest weed control. By using herbicides to prevent excessive growth of weeds such as Russian thistle, kochia, and Palmer amaranth, more soil moisture will be available to stimulate late summer and early fall germination of jointed goatgrass. This will help deplete the soil seed bank.

Keeping stubble free of excessive weed residue will also make the initial weed control operation in the spring more effective. If this initial spring operation will be spraying with glyphosate, coverage and control of small jointed goatgrass plants will be improved if they are not protected by a heavy mat of weed residue. (The use of glyphosate for initial weed control in the spring is a very important management practice for the control of jointed goatgrass and other winter annual grasses, and is discussed further in Appendix B of this bulletin.) If the initial weed control operation in spring will be moldboard plowing, less plant residue will allow more complete burial of remaining jointed goatgrass spikelets.

As you can see, there are a number of benefits from post-harvest weed control. Achieving this control with herbicide, rather than tillage, will increase moisture capture

and decrease soil erosion. Deep tillage, such as ripping or deep chiseling post-harvest, may actually reduce jointed goatgrass control by drying the soil and leaving too many clods for seed germination. However, some research suggests control of jointed goatgrass may sometimes be enhanced by a very light tillage after wheat harvest. The purpose of this light tillage is not immediate weed control. Rather, this light tillage is done to increase spikelet-soil contact and stimulate germination of jointed goatgrass seeds. Otherwise, the seeds in these spikelets may become dormant and remain in the soil seed bank, later emerging and infesting the next crop. By stimulating germination, emerged seedlings can be destroyed by subsequent spraying or tillage, and the soil seed bank reduced more quickly.

Downy brome germination is known to be greatly increased by seed-soil contact, so very light post-harvest tillage helps in its control. Data for jointed goatgrass is less conclusive: in some years, light tillage will have little effect on its germination, whereas in other years, especially under dry conditions, light post-harvest tillage can stimulate germination of jointed goatgrass.

Research has shown that a mulch treader (Figure 8) works well for light tillage, as it incorporates spikelets and other weed seeds without significantly disturbing the soil surface or standing residue. This is important because a rough soil surface or dust from disturbed soil could interfere with later spray applications of glyphosate. Although there is no experimental data for other implements, producers might achieve results similar to using a mulch treader by field cultivating or chiseling stubble very shallowly. (Use points, not sweeps, and just scratch the soil surface at a tractor speed of 7–9 mph. If clods are being brought up, the machine is set too deeply.) When all of the effects are considered—such as saving soil moisture, spraying for later weed control, and minimizing erosion—very light post-harvest tillage might best be used only if: 1) the tillage can be performed in a manner that leaves most stubble attached to the soil and in an upright position, and 2) the soil isn't disturbed enough to make dust a problem during subsequent spray applications of glyphosate.

For fields with only a background population of jointed goatgrass, control of weeds and volunteer wheat from harvest until fall freeze-up may still be beneficial. The reasons discussed earlier still apply, although the need for implementation is not as great as when the infestation is at a critical population and preparation for an intensive reclamation practice is required. Producers will need to compare costs of post-harvest weed control against the anticipated benefits.

Background Control Practices

Throughout the remainder of this bulletin, especially in the section on management at wheat seeding, a number of background control practices will be discussed. These practices are used to help keep background populations of jointed goatgrass from increasing and eventually becoming critical populations. As many background control practices as possible should be part of a producer's normal farming methods. Many of these practices will not only suppress jointed goatgrass and other winter annual grass weeds, but will enhance wheat production in uninfested fields. Examples of background control practices include field border sanitation, proper placement of nitrogen fertilizer, and use of a competitive wheat variety.

Figure 8. Mulch treader.

Background control practices and intensive reclamation practices are complementary. Appropriate background control practices should always be used when an intensive reclamation practice is being implemented. The use of background control practices will help the more intensive practice reclaim land from a critical population of jointed goatgrass. Similarly, an intensive reclamation practice could be used on a field with a background population of jointed goatgrass to ensure that the jointed goatgrass doesn't reach a critical population.

Initial Spring Weed Control for Fields not in a Growing Wheat Crop

The most important thing a producer can do in the spring is to ensure that any jointed goatgrass plants do not mature and produce seed. This is true whether a field will be planted to a spring crop or if it will be held fallow over the summer and then planted to wheat. If the first weed control operation in the spring is not effective and jointed goatgrass seedlings mature and produce seed, any existing problems will then be worse. This may result in a background population becoming a critical population.

Traditionally, tillage with a disk has been the first spring operation for weed control in stubble. Because of cool temperatures and high soil moisture at this time, weeds such as jointed goatgrass, downy brome, and volunteer

rye are often poorly controlled by disking. Unless tillage is required for a spring crop, or the producer is attempting to bury jointed goatgrass spikelets or other weed seeds with a moldboard plow, the best method in early spring to kill jointed goatgrass, downy brome, and volunteer rye seedlings is spraying stubble with glyphosate.

Glyphosate is very effective at killing jointed goatgrass, other grass weeds, and volunteer wheat. It is especially effective in the spring when plants are small and not likely to be under heat or drought stress. However, it is important to apply glyphosate in a timely manner. To prevent production of viable seeds, jointed goatgrass plants should be sprayed no later than emergence of the very first heads; it is best to spray before any heads have emerged.

Most producers spraying stubble for control of jointed goatgrass also will be spraying to control downy brome. Since downy brome typically heads before jointed goatgrass, and should also be sprayed no later than emergence of the first heads, timely spraying of stubble for downy brome control will be early enough for jointed goatgrass control.

For producers who are rotating to a late spring planted crop, initial weed control with glyphosate will allow more cropping options. (Some spring planted crops, such as corn, can only be grown with a no-till system.) For producers who normally use tillage for all summer fallow operations, replacing the first two spring tillage operations with a single spraying of glyphosate saves time, reduces fuel costs, and improves control of jointed goatgrass, downy brome, and volunteer rye. If a producer needs to reduce residue to avoid problems with drills plugging at seeding, then disking can be performed as the first tillage pass in mid to late June. By avoiding tillage until mid to late June, increased residue cover and better soil aggregation decrease erosion and increase moisture capture throughout the fallow period. (For details on using glyphosate as an initial weed control method in the spring, see Appendix B.)

Remember: glyphosate used for initial weed control needs to be part of a multi-practice approach. If a producer uses glyphosate for initial spring weed control on a field that has a critical population of jointed goatgrass, they should plan on rotating to a late spring planted crop for at least two consecutive years or should plan on planting Clearfield™ wheat. If a producer uses glyphosate as a background control practice they should not neglect other background control practices. Remember, seeds that have not germinated will not be controlled by a glyphosate application and those seeds will still be in the soil seed bank.

In certain situations, moldboard plowing as the initial operation for weed control in the spring may be preferred over the use of glyphosate. For various reasons, some producers with a critical population of jointed goatgrass in a field cannot rotate to two or more years of a late spring planted crop. By burying jointed goatgrass spikelets too deep for successful seedling emergence, one-time moldboard plowing may allow reclamation of a field without abandoning a wheat–fallow rotation. Moldboard plowing is also a very effective method for killing jointed goatgrass and other grass weed seedlings in spring conditions that are often too cool and wet for a disk to be effective.

For moldboard plowing to successfully bury jointed goatgrass spikelets too deep for seedling emergence, plowing should be done at least 6–8 inches deep. (Remember, the loose soil after plowing will compress, and jointed goatgrass can emerge through 4 inches of soil.) The plow must also fully invert the soil and thoroughly cover all surface material. Once spikelets are buried, avoid using deep tillage or plowing again for at least four years to prevent bringing seed back up to a level from which it can successfully emerge. It is essential to thoroughly bury and cover jointed goatgrass spikelets by plowing at least 6–8 inches deep, using a plow that does a complete job of inverting the soil and covering surface residue. If the plow bottoms don't cover thoroughly, don't invert soil completely, or if the plow cannot be pulled deeply enough, don't expect this practice to succeed. Also note that deep disking or chiseling will not adequately bury jointed goatgrass spikelets, but will simply distribute them throughout the tilled soil, leaving many at a depth from which seedlings can successfully emerge.

Burning before plowing will not reduce jointed goatgrass seed viability a significant amount unless the surface residue is extremely heavy. Fire temperatures need to be very hot to destroy or sterilize jointed goatgrass seeds, even if they are on the soil surface. Seeds that are shallowly buried, or seeds that are even partially buried, will not be affected by fire. Burning residue also destroys soil organic matter, resulting in decreased soil aggregation, decreased moisture infiltration, and increased erosion. The places where burning might be appropriate are areas within a field that are occasionally shallow ponds. Because of deep soils and moisture accumulation, these areas may produce the high quantity of plant residue necessary for a hot fire.

Seeding Clearfield™ or CoAXium™ wheat into fallow that was moldboard plowed is an additional step that a producer could consider in reclaiming a field from a critical population of jointed goatgrass. This would allow for the use of imazamox herbicide (Beyond™) if plowing does not adequately control the jointed goatgrass. Using CoAXium™ wheat would allow growers to use quizalofop-p-ethyl herbicide (Aggressor™) for control of jointed goatgrass plants. Similarly, a producer might wish to moldboard plow in the fallow year after rotating to spring crops. This would bury any jointed goatgrass seeds that still might be viable. Again, remember that a multi-practice approach to controlling jointed goatgrass relies on combining appropriate practices together to achieve control of the weed.

Finally, in some circumstances, plowing may not be an appropriate practice. Producers may be in areas where soil characteristics or conservation requirements prevent the use of plowing. Individual circumstances and experience

should guide a producer in choosing and combining management practices.

If a producer must use a disk for initial weed control in the spring, the disking operation must be performed before jointed goatgrass and downy brome plants have headed, or they will produce viable seed. If the soil is wet when disked, if the density of weeds and volunteer wheat is thick and the disk turns up slabs of "sod," or if moisture is received before the disked plants are completely dead, the producer should be prepared to quickly perform additional tillage to prevent plants from reestablishing. A producer who uses disking as initial spring weed control on fields with a critical population of jointed goatgrass should also plan to use one or more of the intensive reclamation practices (rotating to a late spring planted crop for at least two consecutive years, moldboard plowing, and/or planting Clearfield™ or CoAXium™ wheat) on those fields.

Field border sanitation is the final component of early spring jointed goatgrass control. Contamination of fields often begins on adjoining road edges or from around power poles and road signs. Pay particular attention along drainage paths and waterways, where seed from other fields may have been deposited by runoff. Prevent the spread of jointed goatgrass from these areas by spot spraying seedlings with glyphosate or otherwise destroying them. Again, it is important to spray seedlings no later than emergence of the very first heads, as jointed goatgrass can produce viable seeds almost immediately after the first heads have emerged. Sometimes in border areas, jointed goatgrass infestations are not identified until many heads have emerged. Plants with fully emerged heads should be physically removed to ensure that no viable seeds are produced. If physical removal is impractical, it is still better to spray these headed plants with glyphosate than to do nothing, as production of viable seeds may be reduced if anthesis has not progressed too far.

Fallow Management After Initial Spring Weed Control

Management of jointed goatgrass should continue during the main summer fallow period between initial weed control in the spring and wheat seeding in the fall. Little jointed goatgrass is likely to emerge during this time, other than a late August or early September flush. Obviously, if this flush occurs, these jointed goatgrass plants should be destroyed prior to seeding wheat. However, even in the absence of growing plants, there are steps a producer can take to enhance long term jointed goatgrass control.

For producers who used moldboard plowing as the initial operation for weed control in the spring, subsequent summer fallow weed control should avoid deep tillage that might pull buried spikelets back up to a depth from which jointed goatgrass can emerge. Shallow tillage with small sweeps, field cultivators, and rod attachments will kill weeds and prepare a seedbed without disturbing buried jointed goatgrass spikelets.

For producers who used glyphosate as the initial operation for weed control in the spring, subsequent weed control can be done with either herbicides or tillage. For jointed goatgrass management, there is probably no difference between the use of herbicides or tillage for weed control during the summer months of the fallow period. Instead, growers should use the system that they feel provides them with the best seedbed for the upcoming wheat crop. Similarly, producers who used a disk for initial weed control in the spring should use subsequent tillage operations that will prepare the best seedbed. A good seedbed will help establish a vigorous, competitive crop of wheat. A vigorous, competitive crop will suppress jointed goatgrass and is one of the most important factors keeping background populations from becoming critical populations.

Proper application of nitrogen fertilizer is an important background control practice for the management of both jointed goatgrass and downy brome, with both the timing of application and placement of nitrogen as critical factors. Nitrogen fertilizer, other than small amounts of starter fertilizer used at seeding, should be applied as early as practical in the fallow season. Rainfall can then move the nitrogen deeper into the soil profile, allowing wheat roots to access the nitrogen before roots of later germinating jointed goatgrass can reach it. Nitrogen that has moved deeper into the soil profile is also less accessible to the shallow root system of downy brome. One exception to the early fallow application of nitrogen would be the use of seeding equipment that can band high rates of nitrogen below and to the side of the row at seeding. Nitrogen placed in this manner will be deep enough in the soil profile that wheat can access it before the later germinating weeds can.

Spring topdressing of nitrogen fertilizer onto growing wheat is not recommended when wheat is infested with jointed goatgrass or downy brome. Research has shown that these weeds are very effective in capturing surface-applied nitrogen, increasing their competitiveness with wheat. Where winter annual grass weeds are a concern, nitrogen applications in growing wheat should be made with a coulter applicator or other machine that can place nitrogen several inches below the soil surface.

Management at Wheat Seeding

At seeding, producers should pay particular attention to management practices that enhance **crop competitiveness:** the ability of a thick, vigorous, healthy stand of wheat to out-compete jointed goatgrass by capturing more of the sunlight, soil moisture, and soil nutrients available for plant growth. A competitive crop results in fewer and smaller jointed goatgrass plants that don't significantly reduce wheat yields. Smaller jointed goatgrass plants also produce fewer spikelets and seeds, reducing infestations in subsequent wheat crops. A competitive crop alone will not reclaim a field from a critical infestation of jointed goatgrass, but it will enhance the use of crop rotation, one-time moldboard plowing, and

Clearfield™ and/or CoAXium™ wheat in reclamation. For fields with a background population of jointed goatgrass, growing a competitive crop is one of the most important practices a producer can do to help keep them from becoming critical infestations.

As we discussed earlier, in a multi-practice approach to controlling jointed goatgrass, a producer combines several appropriate management practices to achieve better jointed goatgrass control than could be obtained by relying on only one or two practices. Increasing crop competitiveness by using as many of the following background control practices as possible at seeding time is one of the best ways to implement a multi-practice approach. Even though many of these practices would have a limited effect if used alone, when combined and used over a period of years, the results will be significant.

Plant a competitive variety. Varieties with quick emergence, rapid growth, prolific tillering, and tall plant height suppress jointed goatgrass better than varieties that don't exhibit these characteristics. It is also important to plant a variety that is adapted to the producer's location. A rapidly emerging, tall variety will provide little weed suppression if it has poor winter survival.

Use clean seed. Make sure wheat seed doesn't contain jointed goatgrass spikelets or other weed seeds. Do not create a problem by planting contaminated wheat seed. Producers using bin-run seed should use a cleaner that will remove jointed goatgrass spikelets. Producers purchasing certified seed should make sure it contains no jointed goatgrass spikelets. To determine if jointed goatgrass is present in wheat seed, place a seed sample into a pail, cover with water, and stir. Wheat seeds sink, whereas jointed goatgrass spikelets float.

Consider the seeding date. Most areas have a five to ten day period that is considered optimum for wheat planting. In order to cover all of their acres, producers begin planting before the optimum period and/or finish planting after the optimum period. Fields in which jointed goatgrass is a concern should be planted during the optimum period to ensure a competitive stand. If fields are planted too early, there is a risk of missing a flush of jointed goatgrass that could be destroyed before seeding. If fields are planted too late, the wheat will emerge too late and be less competitive with jointed goatgrass. Even though later seeding might slightly increase the chances of eliminating a flush of jointed goatgrass before seeding, this event is very weather dependent. Over several years, the gains from killing an occasional flush of jointed goatgrass are more than offset by the decreased competitiveness of wheat that is seeded too late.

Use quality seed. The total amount of protein in a seed, not the protein percentage, is important to early seedling vigor. More total protein will result in a more vigorous seedling. Large seed may have a lower protein percentage than small seed, but because the large seed weighs more, it can have a greater total amount of protein per seed. For example: a batch of large seed (13,500 seeds per pound) with 11% protein, will average 3.7 mg of protein per seed. A batch of small seed (20,000 seeds per pound) with 13% protein, will average 2.9 mg of protein per seed.

Consider Seed Size. The size of wheat seed can be described using the number of seeds per pound. Seed from 10,000 to 13,000 seeds per pound can be considered large; seed from 13,000 to 16,000 seeds per pound considered medium; seed from 16,000 to 20,000 seeds per pound considered small; and seed with more than 20,000 seeds per pound considered very small. Note, as the number of seeds per pound increases, seed size is decreasing. Although variety and actual seeding rate (seeding rate is discussed below) are more important for crop competitiveness and crop yield than seed size, producers may want to plant medium or large seed. With a given variety and seeding rate, medium or large seed may result in a more vigorous seedling and a plant that can better compete with jointed goatgrass. In some years, small seed may have to be used, but very small seed (more than 20,000 seeds per pound) should be avoided.

It is easy to determine the number of wheat seeds per pound. Most grain elevators have a digital scale accurate to 0.1 grams that is used for dockage measurements. A scale at least this precise is needed for accurate results. Count 250 seeds and have them weighed in grams. Use the following formula to convert from this weight in grams to seeds per pound: (250 ÷ weight in grams) x 454 = seeds per pound.

Consider the effect of seed size on actual seeding rate. Although wheat is commonly seeded in pounds per acre, it is actually **seeds per acre** that is the important number in determining initial stands. Wheat seed can vary in size from less than 13,000 seeds per pound (large seed) to more than 20,000 seeds per pound (very small seed). If a producer is simply planting wheat by pounds of seed per acre, the actual number of seeds planted per acre and the resulting stand of wheat can vary widely.

Consider, for example, a producer who typically plants 40 pounds of seed per acre without compensating for seed size. If, in normal years, seed size has been 13,000 seeds per pound, the seeding rate has been approximately 520,000 seeds per acre (40 x 13,000). In a year when seed was affected by drought and is smaller, 18,000 seeds per pound, the producer will be planting almost 38% more seeds per acre (40 x 18,000 = 720,000) if the pounds per acre seeding rate is not adjusted. If the normal rate of 520,000 seeds per acre gave proper stands, the producer is now seeding at too heavy a rate. This is wasting money by needlessly planting extra seed and wasting time by filling drills more often than necessary. In drier regions, yields may be hurt by too many plants, which use up too much moisture. No good producer would randomly select a seeding rate, or pay no attention to drill settings. Why let differences in seed size effectively do the same things?

Similarly, if the producer has been using a correct rate in pounds per acre with small seed and then uses a batch of

seed that is larger, the seeding rate may become too low for optimum yield. Although wheat can compensate for different seeding rates by adjusting tiller numbers and head size, seeding rates too high or too low can hurt yields, and should be avoided.

Experience, seed suppliers, and extension specialists can guide producers in determining how many seeds per acre are appropriate for their location, seeding date, and conditions. (See also the next section of this bulletin, "Adjust seeding rates for seeding date and for weed suppression.") Producers can use the method previously discussed in the "Consider seed size" section of this bulletin to determine number of seeds per pound for any given batch of seed. It is then a matter of simple math to calculate how many pounds of seed per acre are actually needed to provide the desired number of seeds per acre. Even if rate adjustments allowed by seeding equipment aren't precise enough to meter exactly the desired number of seeds per acre, results will still be more accurate than not compensating for seed size.

Adjust seeding rates for seeding date and for weed suppression. Seeding rates should be increased as the seeding date becomes later. Also, seeding rates should be increased at least 20% over the normal seeding rate for any given seeding date, if suppression of jointed goatgrass is desired.

For example, the optimum period for planting winter wheat in Cheyenne County, Nebraska, is between September 10 and September 20. A normal seeding rate on September 10 is approximately 520,000 seeds per acre. (35 pounds per acre at a seed size of 15,000 seeds per pound, or 40 pounds per acre at a seed size of 13,000 seeds per pound.) A normal seeding rate on September 20 is higher, to compensate for later emergence and decreased tillering. And a normal seeding rate on September 30 would be even higher, for the same reasons. A normal seeding rate on September 20 is approximately 820,000 seeds per acre. (55 pounds per acre at 15,000 seeds per pound, or 63 pounds per acre at 13,000 seeds per pound.) These normal seeding rates are for fields where jointed goatgrass suppression is not required. In fields where suppression of jointed goatgrass is desired, the seeding rate for any given date should be increased by at least 20% over the normal rate for that date. Therefore, to help in suppression of jointed goatgrass, the desired seeding rate for Cheyenne County, Nebraska, on September 10 would be at least 624,000 seeds per acre (42 pounds per acre at 15,000 seeds per pound, or 48 pounds per acre at 13,000 seeds per pound). The rate on September 20 would be at least 984,000 seeds per acre (65 pounds per acre at 15,000 seeds per pound, or 75 pounds per acre at 13,000 seeds per pound).

The optimum planting period and normal planting rate for any given day in that period changes by location. The example discussed above is for Cheyenne County, Nebraska. Experience, extension specialists, and seed suppliers can guide producers in selecting normal seeding rates and the optimum seeding period in their particular location.

Apply starter fertilizer. Many soils in the region covered by this bulletin have phosphorus levels too low for optimum wheat production. Years of farming have reduced soil nitrogen levels to a point where fertilizer nitrogen is required. Soil tests can help producers determine the amount of these nutrients to apply.

Unless specialized seeding equipment is available to band nitrogen below the seed, the majority of nitrogen fertilizer should be applied as early as possible in the fallow season. Reasons for this were discussed earlier in this bulletin. Phosphorus fertilizer, however, can be band-applied with the seed. Banding phosphorus fertilizer with the seed, in amounts based on soil test recommendations, is one of the most important practices to promote vigorous growth and maximum yields of wheat. Wheat that is growing vigorously will help suppress jointed goatgrass.

Figure 9a. Disc drill modified to place liquid starter fertilizer in the seed row.

Figure 9b. Hoe drill modified to place liquid starter fertilizer in the seed row.

Typical rates of phosphorus fertilizer don't contain enough nitrogen to inhibit germination, even when the fertilizer is placed directly with the seed. This makes it relatively easy to retrofit older seeding equipment to apply liquid phosphate fertilizer (Figures 9a and 9b). (Note: make sure that fertilizer placed with the seed DOES NOT contain Ammonium Thiosulfate, 12-0-0-26. This product will severely reduce seedling germination.) Fertilizer dealers can supply information on retrofitting seeding equipment. Also, some producers apply phosphorus fertilizer with older seeding equipment by simply blending dry 11-52-0 or 18-46-0 with the seed.

Consider row spacing. In general, narrow row spacing is more effective in suppressing jointed goatgrass and other weeds than wider row spacing. As with other background control practices that can be used at seeding, narrow row spacing by itself will not suppress a background population, nor will it reclaim land from a critical infestation. Over several years, however, when used in conjunction with other background control practices, narrow row spacing can help suppress a background population of jointed goatgrass or help an intensive reclamation practice be more effective.

Although weed suppression from narrow row spacing is a factor, it is more important to establish a good stand of wheat than it is to have narrow rows. In drier regions, hoe openers with wider spacing may be needed to move dry soil into the ridge between rows so that wheat seed can be placed into moist soil without burying the seed too deeply. A row spacing of 10 inches might be considered narrow in these regions. In wetter areas, a row spacing of 6 or 7.5 inches might be considered narrow. Experience and equipment availability should guide producer decisions. It is unlikely that changing seeding equipment to obtain additional weed control from narrow row spacing would be cost effective, especially if the producer has implemented the other background management practices suggested for use at seeding. However, if equipment is being changed for other reasons, narrow row spacing should be considered.

Grow Clearfield™ or CoAXium™ wheat. In addition to selecting from the above background control practices, producers have the option of using a Clearfield™ or CoAXium™ wheat variety. This can be done as either an intensive reclamation practice or occasionally as a background control practice. Clearfield™ wheat varieties allow the growing wheat to be sprayed with an imazamox herbicide, such as Beyond™. Imazamox herbicide will kill or suppress jointed goatgrass, downy brome, and volunteer rye plants that have emerged in the wheat. CoAXium™ wheat varieties allow the growing wheat to be sprayed with Aggressor herbicide. Aggressor herbicide applied at the recommended field-use rate will control jointed goatgrass in growing wheat. Recent research with CoAXium™ wheat in the Central Great Plains has shown that Aggressor herbicide applied in fall or spring can provide effective control of jointed goatgrass (See Aggressor label for specific use instructions and for controlling other winter annual grass weeds). Because Clearfield™ or CoAXium™ wheat varieties contain a gene or genes that makes them tolerant to imazamox (Clearfield™) or quizalofop-p-ethyl (CoAXium™), they may be sprayed with the appropriate herbicide with minimal risk of crop injury. **Winter wheat varieties that do not contain this gene or genes (that provides tolerance to imazamox or quizalofop-p-ethyl), will be severely injured or killed if treated with one of these herbicides.** Clearfield™ and CoAXium™ wheat varieties are not Genetically Modified Organisms (GMOs). The gene or genes that makes them tolerant to imazamox or quizalofop-p-ethyl herbicide were introduced using standard plant breeding techniques.

Producers using Clearfield™ or CoAXium™ wheat varieties should also implement as many other jointed goatgrass control practices as practical. Using crop rotation or moldboard plowing before planting Clearfield™ or CoAXium™ wheat on fields that had a critical population will significantly reduce the number of jointed goatgrass plants that the herbicide must control in the wheat. Although imazamox has been shown to provide 90% or greater control of jointed goatgrass, final results will be better if there are fewer plants to control at the time of imazamox application.

Note: Producers purchasing Clearfield™ or CoAXium™ wheat seed must sign a contract agreeing to comply with the Clearfield™ or CoAXium™ Stewardship Program. Further details about Clearfield™ or CoAXium™ wheat, the Stewardship Program, and information on applying imazamox or quizalofop-p-ethyl herbicides, are discussed below.

Management in the Growing Wheat

Management of jointed goatgrass in the growing wheat crop begins with identifying infestations. The identification and biology section earlier in this bulletin contains pictures and descriptions that can be used to determine if small plants are jointed goatgrass, downy brome, or wheat. Check for and identify plants growing between the wheat rows (Figure 10). Pay particular attention to field edges, low areas that are sometimes ponded, and along waterways where jointed goatgrass seed from other fields may have been deposited during runoff.

As discussed earlier, **topdressing nitrogen fertilizer onto growing wheat is not recommended when wheat is infested with jointed goatgrass or downy brome.** Research has shown that these weeds are very effective in capturing surface-applied nitrogen, increasing their competitiveness with the wheat crop. Where winter annual grass weeds are a concern, nitrogen applications in growing wheat should be made with a coulter applicator or other machine that can place the nitrogen several inches below the soil surface. One exception to this is the use of UAN nitrogen solution diluted with water as the carrier when spraying Beyond™ herbicide. In this

instance, the herbicide will control jointed goatgrass or downy brome, thus the nitrogen will not be used by the weeds. Remember, **imazamox or quizalafop-p-ethyl herbicides such as Beyond™ or Aggressor™ can only be used on Clearfield™ or Aggressor™ wheat, respectively. These herbicides will kill or severely damage other varieties.**

For fields that cannot be sprayed with Beyond™ or Aggressor™ herbicide, (or for fields of Clearfield™ or CoAXium™ wheat that will not be sprayed) small patches of wheat that are densely infested with jointed goatgrass should be destroyed by tillage or by spraying with glyphosate. This is especially true if the field is otherwise not infested or has only a low background population of jointed goatgrass. It is important to spray these patches no later than emergence of the first jointed goatgrass heads. Ideally they should be sprayed before any jointed goatgrass heads emerge. Tillage to kill these patches should be performed **before** any heads emerge. It is better to lose a small amount of wheat by destroying an infested patch or field edge, than to allow jointed goatgrass to spread and become a critical infestation over an entire field. Remember, a combine can do an excellent job of spreading weed seeds further into a field.

Figure 10. Jointed goatgrass growing between wheat rows.

In some years, drought or other natural disasters may severely damage a wheat crop by early spring. If this crop was infested with jointed goatgrass or other winter annual weeds, even at only a low or moderate level, destroying an entire field or fields may be advisable. Interrupting the normal life cycle of winter annual grass weeds by destroying them in a spring when they otherwise would produce seed, is a very effective control practice. Again, as in destroying small patches, spraying glyphosate to kill jointed goatgrass should be performed no later than the emergence of the first heads. Tillage to control jointed goatgrass should be done before any heads emerge. It is not advisable to try controlling jointed goatgrass by grazing or haying an infested field. Cattle may selectively graze wheat in preference to jointed goatgrass, giving jointed goatgrass a significant competitive advantage. Haying of wheat would likely be done after jointed goatgrass had already produced seed. Typically, not all of this seed is removed from the field with the hay. In addition, mowing jointed goatgrass will not kill the plants, and they may produce new tillers with additional seed. Also, feeding infested hay to cattle can spread jointed goatgrass through viable seed in the manure.

Just as with fallow fields in early spring, field border sanitation around growing wheat is a very important control practice. Contamination of fields often begins on adjoining road edges or from around power poles and road signs. Pay particular attention along drainage paths and waterways, where seed from other fields may have been deposited by runoff. Prevent the spread of jointed goatgrass from these areas by spot spraying seedlings with glyphosate or otherwise destroying them. Jointed goatgrass plants with fully emerged heads may have to be physically removed to ensure that no viable seed is produced. If physical removal is impractical, it is still better to spray these headed plants with glyphosate than to do nothing, as production of viable seeds may be reduced if anthesis has not progressed too far.

Fields planted to a Clearfield™ or CoAXium™ wheat variety have an additional management practice available for control of jointed goatgrass, downy brome, and volunteer rye: in-crop application of an imazamox (Beyond™) or quizalofop-p-ethyl (Aggressor™) herbicide, respectively. These products should be applied according to label instructions. ALWAYS READ AND FOLLOW LABEL DIRECTIONS CAREFULLY!

In field research studies conducted throughout the Central Great Plains, use of Beyond™ has provided good (90%+) control of jointed goatgrass and downy brome when weeds were treated with 4 ounces of product per acre in the fall or early spring. Fair (80%+) control of volunteer rye required an early fall application with 5 ounces of product per acre. **(This rate is only registered for Clearfield™ winter wheat; it is not registered for Clearfield™ spring wheat).** For control of volunteer rye, it is important to make the spray application in the fall, before the first tiller of the plant has formed, as later applications of Beyond™ rarely provided acceptable control.

Although imazamox herbicides typically provide good control of jointed goatgrass, environmental conditions such as drought or cold temperatures may reduce their effectiveness. Also, imazamox will not provide residual control of any seeds in the soil seed bank—further demonstrating the need for producers to use a multi-practice approach in managing problem weeds.

Among weed scientists, the biggest concern with the use of Clearfield™ wheat is the potential for development of

herbicide-resistant weeds. Because imazamox provides good control of jointed goatgrass and downy brome, it will exert a tremendous selection pressure for resistance. Imazamox belongs to a class of herbicides known as ALS-inhibitors. Other herbicides in this class have a history of quickly selecting for weeds that are herbicide resistant. Examples include ALS-resistant kochia, prickly lettuce, and pigweed.

CoAXium™ is another herbicide-tolerant wheat in which growers can spray quizalofop-p-ethyl (Aggressor™) herbicide to control grass weeds, including jointed goatgrass, downy brome, and feral rye. Field studies in the Central Great Plains have shown that fall or spring applications of Aggressor™ at 8 fl oz/a can provide excellent control of jointed goatgrass in CoAXium™ wheat.

To delay the onset of herbicide resistance, fields treated with imazamox herbicides should not be treated with another ALS-inhibitor in the same year. Because many wheat herbicides are ALS-inhibitors, producers will need to be careful in choosing additional treatments. If additional weed control is needed, such as for controlling warm season broadleaf weeds like kochia or pigweed, herbicides with a different mode of action should be used. Herbicides containing 2,4-D or dicamba are examples. Consult herbicide labels or university weed control guides for further information.

Herbicide resistance might also occur through pollen transfer, because jointed goatgrass and wheat share a common ancestor. Research has shown that there is a slight chance of moving the gene that is resistant to imazamox from a Clearfield™ wheat variety to jointed goatgrass. For further information on the genetics of wheat and jointed goatgrass, see "Jointed Goatgrass Genetics" (Washington State University EB1943) available at *www.jointedgoatgrass.wsu.edu* or from university extension specialists.

Producers planting Clearfield™ or CoAXium™ wheat are required to comply with a Stewardship Program in order to help reduce the development of herbicide resistance. This program requires that producers always plant certified seed. In order to purchase their first Clearfield™ or CoAXium™ wheat seed, growers must sign an agreement saying that they will not save any grain from their crop of Clearfield™ or CoAXium™ wheat to be used as seed for a subsequent crop.

The Stewardship Program also requires that imazamox herbicide be used not more than twice in any four-year period. This allows producers in a wheat–fallow rotation to use Clearfield™ wheat every time they plant wheat. Producers in wheat–fallow rotations may want to consider limiting their use of Clearfield™ wheat and imazamox herbicide to no more than twice in any six-year period. This will help minimize the potential of developing herbicide resistance.

Producers interested in using Clearfield™ or CoAXium™ wheat should consult with their seed supplier or chemical dealer for full details on the Stewardship Program. Producers are required to enter into a contractual agreement covering the Stewardship Program in order to purchase Clearfield™ or CoAXium™ wheat seed.

Scientists working as part of the National Jointed Goatgrass Research Program are investigating herbicide resistance related to jointed goatgrass. Further information on herbicide resistance can be found in EM024E, Strategies to Minimize Risk of Herbicide-Resistant Jointed Goatgrass, available at *www.jointedgoatgrass.wsu.edu*

Summary

Throughout this bulletin, the use of a multi-tactic approach to control jointed goatgrass has been emphasized. The large year-to-year variations in precipitation and growing conditions in the western part of the Central Great Plains will greatly influence the effectiveness of any one practice in a given year. This makes the use of multiple practices particularly important. A producer who relies on only one practice, or on practices implemented at only one part of the cropping cycle, will not be successful at long-term control of jointed goatgrass or other winter annual grass weeds.

A multi-tactic approach can effectively control jointed goatgrass and other winter annual grasses for dryland wheat producers. With this approach, producers can limit the negative economic and environmental impacts of these weeds.

The practices discussed in this bulletin are documented by multiple years of research in Kansas, Nebraska, Colorado, and Wyoming. Detailed research reports can be found at *www.jointedgoatgrass.wsu.edu*

Appendix A. Post-Harvest Weed Control with Herbicides

There is no set procedure for general weed control in stubble from winter wheat harvest until fall freeze-up. Weed density, weed species, and rate of weed growth will all vary from field to field and from year to year. Producers need to evaluate each situation and use practices appropriate for their situation to achieve success.

Post-harvest weed control will be easier if the winter wheat crop was thick and vigorous enough to suppress weeds and/or weeds were controlled within the crop. Producers who use a stripper header to harvest wheat often find the tall stubble helps suppress weed growth after harvest.

If stubble is free of high-water-use plants such as Russian thistle and kochia, if volunteer wheat density is low, and if other weeds are small and not likely to produce seed, it may be possible to postpone weed control until early fall. At that time a flush of grass weeds such as volunteer wheat, jointed goatgrass, downy brome, and volunteer rye may emerge. This early fall flush should be controlled by spraying with glyphosate to prevent water use during the fall and winter, and to allow further germination of additional seeds. Additional seedlings that emerge after an early fall treatment

won't consume significant water over the winter and can be destroyed in the spring, further depleting the soil seed bank. Producers can also add atrazine to the early fall treatment, at a rate appropriate to their soil type and crop rotation, to help control these late fall seedlings.

If stubble becomes weedy shortly after harvest, especially if the weeds are high-water-use plants such as Russian thistle and kochia, split herbicide applications may have to be used. The first application, typically within two to four weeks after harvest, is to kill weeds that are actively growing post-harvest. The second application, in early fall, will kill any early fall flush of volunteer wheat and other winter annual grass weeds.

Split applications have a good history of effectiveness, and their additional cost can be justified if a spring planted crop such as corn, grain sorghum, sunflower, or proso millet is next in the rotation. In Kansas, there have been 20-bushel increases in corn yields when initial wheat stubble weed control began in July rather than mid-August.

The herbicide generally used for the first treatment in a split application is glyphosate (the active ingredient in products such as Roundup®, Buccaneer®, Gly Star™, etc.). Glyphosate is typically tank-mixed with 2,4-D or dicamba to adequately control weed species growing during July and August. With increasing cases of glyphosate-resistant kochia and Palmer amaranth in the Central Great Plains in recent years, other burn down chemistries including paraquat, saflufencail, and glufosinate are also used in post wheat harvest situations. Detailed information on appropriate herbicides for control of various weed species can be obtained from chemical suppliers, university extension materials, and from herbicide labels. ALWAYS READ AND FOLLOW LABEL DIRECTIONS CAREFULLY!

Weeds in summer are often under stress and can be difficult to control with herbicides. Try to spray weeds when stress can be minimized. Avoid spraying when temperatures exceed 90° F. If weeds are under drought stress, try to wait for rain and then spray about five days later. Weeds that have been cut off with the combine should be given a chance to begin re-growth before spraying. Do not wait too long however, as large weeds are more difficult to control.

When using glyphosate, it is always advisable to add spray-grade ammonium sulfate (AMS) as an adjuvant in the spray solution at a rate of 17 pounds per 100 gallons of spray solution. Spray solution is the total tank mixture being applied through the sprayer: herbicides, any surfactants or other adjuvants, and water. Note: It is especially important to use a 17-pound rate of AMS when spraying weeds under stress conditions such as drought. If liquid AMS is used, it is still important to use enough of the product to obtain the equivalent of 17 pounds of dry AMS per 100 gallons of spray solution. (This may require 5 gallons of liquid AMS per 100 gallons of spray solution. Check the label.) When filling the sprayer, add AMS to the water before adding glyphosate to allow the AMS to react with and neutralize any elements such as calcium or magnesium in the water. If these elements are not neutralized they can "tie up" some of the glyphosate and reduce the effectiveness of the spray.

Producers should also consider the amount of **nonionic surfactant (NIS)** in their spray solution. Some glyphosate products provide a "partial load" of NIS, while other products provide no NIS. Both of these generally require the addition of NIS to the tank mixture, typically at a rate of 2 quarts NIS per 100 gallons of spray solution. Some glyphosate products are advertised as "fully loaded" and producers assume that these products will provide adequate NIS. Remember, however, the amount of NIS needed is determined by the **total volume** of spray solution (including water), while the amount of NIS provided by a "fully loaded" product is determined by how much glyphosate product is being added to the total volume of spray solution. At glyphosate rates lower than the full labeled rate, especially with higher water volumes, "fully loaded" glyphosate products may not be providing enough NIS for the total volume of spray solution. Check the label on all glyphosate products to see if additional surfactant is recommended or allowed. Chemical suppliers and university extension specialists can provide further information on surfactant use.

The second part of a split application (or the initial control operation if weeds were not a problem in the stubble during July and August and did not require the first part of a split application) should be done in early fall after any flush of volunteer wheat or other winter annual grass weeds have emerged. Glyphosate typically works well in these early fall conditions. Temperatures are moderate, and if moisture has been received weeds will be actively growing. Also, the target weeds at this time (volunteer wheat, volunteer rye, jointed goatgrass, and downy brome) are more easily controlled by glyphosate than many summer broadleaf weeds. Producers using glyphosate should continue to use AMS and NIS (if NIS is allowed by the label), as they will enhance weed control. If atrazine is desired for residual control, it can also be applied at this time; however, atrazine in a tank mix with glyphosate may require the use of additional glyphosate to compensate for antagonism between the herbicides. Again, read and follow the herbicide label.

Finally, there is one special case where it is essential to control unwanted plant growth in stubble soon after harvest: when hail shatters viable wheat seed onto the ground and it germinates before or by harvest, it is very important to kill the "green bridge" of volunteer wheat. This will prevent the volunteer wheat from becoming a host for the wheat curl mite, which transmits wheat streak mosaic virus. If the mite has uninterrupted access to green wheat (the crop in early summer and volunteer wheat from harvest until fall-seeded wheat emerges) it can reproduce in large numbers and heavily infest fall seedlings. This will result in wheat streak mosaic severely damaging or destroying the fall-seeded wheat crop in that area. The size of the area infected and damaged will depend on wind speed, wind direction, and distance from the infected volunteer wheat. If volunteer wheat emerges before or by

harvest, it is important to provide a "gap" of at least two weeks without green volunteer wheat in the stubble before the next crop is planted.

Appendix B: Glyphosate as an Initial Weed Control Method in the Spring

Historically, producers in wheat–fallow rotations have used tillage throughout the fallow period for weed control. Herbicides replaced tillage only when producers had a wheat–spring planted crop–fallow rotation. However, reduced glyphosate prices are now allowing wheat–fallow farmers to use a reduced-till system by replacing initial spring tillage operations with an application of glyphosate.

Spring conditions are well suited for replacing tillage with a glyphosate application. Adequate moisture and moderate temperatures typically provide for active weed growth and glyphosate provides excellent weed control under these conditions, especially with the weed species most common at this time: volunteer wheat, jointed goatgrass, downy brome, and volunteer rye. These same conditions often make control of these species difficult with tillage. It is very common to disk a field in the spring, only to have re-growth or, even worse, heading and seed production by weeds, due to damp conditions, cool weather, or a small amount of rainfall.

In addition to better weed control, replacing initial spring tillage operations with an application of glyphosate preserves residue and soil structure. This increases moisture capture and decreases erosion during the high rainfall months of May and June, and helps prevent soil compaction by avoiding tillage on wet soils. Delaying initial tillage until at least mid-June also provides better residue cover and soil structure (resulting in better moisture infiltration and decreased erosion) throughout the remainder of the fallow period and into wheat seeding. Better aggregation of soil particles will also help prevent wind erosion in the growing wheat crop.

Note that this reduced-till system doesn't require a producer to do all fallow weed control with herbicides. If a producer needs to reduce residue in order to seed with conventional drills, or prefers to use tillage for summer weed control (when weed species, temperature and moisture conditions may not be as favorable for the use of glyphosate) that option is available. Simply begin tillage in mid-June with a disk, sweeps, or another appropriate implement and continue to use tillage as required until fall seeding. This tillage will also provide a layer of loose soil above the soil moisture line, which will insulate against seed zone moisture loss in the event of a late summer drought.

Producers using glyphosate in the spring should add spray grade ammonium sulfate (AMS) and nonionic surfactant (NIS) (if additional surfactant is required and allowed by the label) as discussed in Appendix A of this bulletin. If weed species other than grass weeds are present, tank mixes containing 2,4-D and/or dicamba may be required to control these other species.

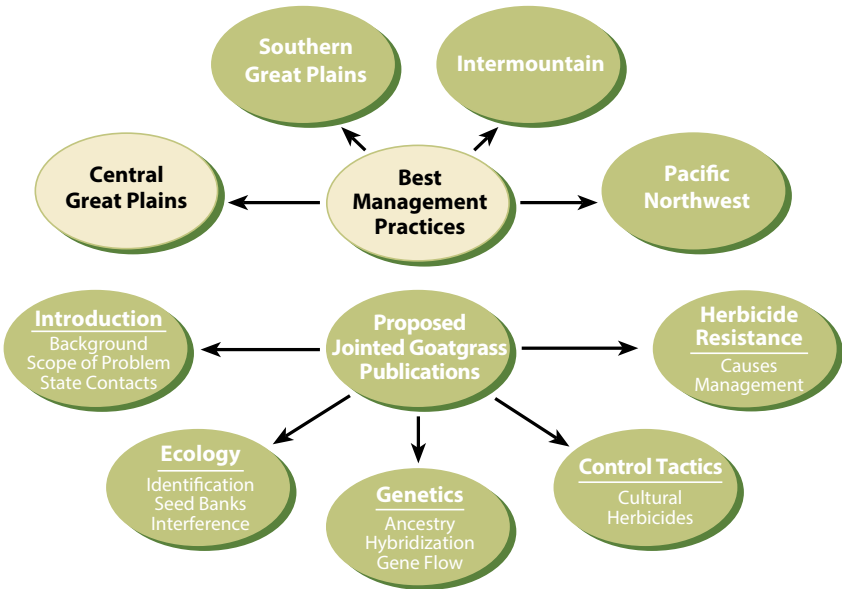
Adequate coverage during spring glyphosate application is very important. Often stubble is soddy, with a large number of very small grass weeds and volunteer wheat plants. To kill all the plants, a spray droplet must contact at least one leaf on every plant. Spray volume per acre must be great enough for adequate coverage, typically not less than 7 gallons per acre. Spray volume should not be excessive however, as the droplets hitting the plants will have to dilute a chemical concentration, which reduces the effectiveness of glyphosate. To ensure coverage in the sprayer wheel tracks, increase the size of tips that spray the tracked area to provide a rate 25% to 50% greater than the rate provided by other tips on the boom. (Do not increase tip size so much that more than the maximum labeled rate of herbicide will be applied.)

Sprayers are commonly equipped with 80° spray tips on 20-inch centers and have boom height set for a spray pattern overlap of 30%. Equal or better coverage can be achieved by changing to 110° tips on 30-inch centers with boom height set to provide 100% overlap. By using 110° tips on 30-inch centers rather than 80° tips on 20-inch centers, larger size tips can be used for any given spray volume. This reduces the chances of plugging screens or tips, especially if the larger size tip allows the use of 50-mesh rather than smaller 100-mesh tip screens. The number of nozzle bodies, tips, and tip screens to buy, clean, and maintain can also be reduced by one-third. To obtain 100% overlap of the spray pattern with 110° tips, sprayer boom height should be adjusted to provide at least 24 inches between the spray tip and the top of the plant being sprayed. If spraying in rough conditions, allow extra distance to compensate for boom bounce.

Note: the 24-inch distance discussed above is not measured straight up and down, but is measured at the same angle as tip orientation. On a sprayer equipped with windscreens, the tips are typically angled forward to spray midway between the windscreens. Without windscreens, the tips should be angled 10° to 25° past a straight down position and towards the rear of the sprayer.

Producers also need to carefully evaluate the relationship between spray drift and coverage. For a given spray volume in gallons per acre, smaller tips (110° tips rather than 80° tips) and increased pressure will result in finer spray droplets that provide more thorough coverage. However, it is important not to have droplets so small that they drift excessively, reducing coverage and possibly damaging nearby crops or desirable vegetation. Extension specialists can provide further information on controlling drift while maximizing spray effectiveness.

Finally, don't expect optimum performance from a spring application of glyphosate if the field was disked or undercut the previous summer or fall. Loose soil can create excessive dust and reduce herbicide performance. A rough soil surface can also cause excessive boom bounce, making coverage uneven.



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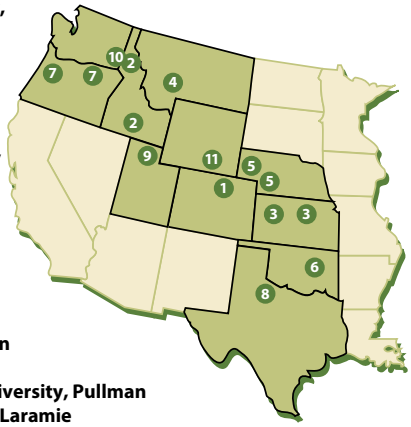
1–Colorado—Colorado State University, Ft. Collins
2–Idaho—University of Idaho, Moscow & Twin Falls
3–Kansas—Kansas State University, Hays & Manhattan
4–Montana—Montana State University, Bozeman
5–Nebraska—University of Nebraska, North Platte & Scottsbluff
6–Oklahoma—Oklahoma State University, Stillwater
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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