Effects of Safflower (A Spring Crop), and Wheat Planting Date on Controlling Jointed Goatgrass (*Aegilops cylindrica*) in Winter Wheat

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EFFECTS OF SAFFLOWER (A SPRING CROP), AND WHEAT PLANTING DATE ON CONTROLLING JOINTED GOATGRASS (*AEGILOPS CYLINDRICA*) IN WINTER WHEAT

by

Caleb Dale Dalley

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ABSTRACT

Effects of Safflower (a Spring Crop), and Wheat Planting Date on Controlling Jointed Goatgrass (*Aegilops Cylindrica*) in Winter Wheat

by

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Utah State University, 1999

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To improve management and control of jointed goatgrass (*Aegilops cylindrica* Host.) on traditional winter wheat (*Triticum aestivum* L.) cropland, a better understanding of the effects spring crop and wheat planting date have on weed populations and wheat yield is needed. A study of the effects of safflower (a spring crop) and wheat planting dates (early vs late) was conducted over a 2-yr period. Long term effects will be examined over a 5-yr period. The effects these treatments had on yield, weed seed contamination, jointed goatgrass population density, and soil seedbank concentration were measured. Two identical experiments were initiated, the first beginning in 1996, the second in 1997.

In experiment one, initial plant counts showed similar numbers of jointed goatgrass plants in all treatments. In experiment two, initial spring plant counts showed increased numbers of jointed goatgrass in unplanted plots prior to planting safflower, and slightly reduced population densities in October-planted wheat when compared to

September-planted wheat. Winter wheat yields were 25% and 35% higher in September-planted wheat than in October-planted wheat, in 1997 in experiment one, and 1998 in experiment two, respectively. Crop contamination with jointed goatgrass propagules was four times higher in early vs late-planted wheat in 1997, and 36% higher in 1998. Jointed goatgrass plants in safflower were reduced 97% compared to preplant counts in both experiments. In experiment one, 1998 fallow season plant counts showed 55% and 75% less jointed goatgrass in fallow safflower plots than in fallow plots of September- and October-planted wheat, respectively, with fallow plots of September-planted wheat having 46% less than fallow plots of October-planted wheat. Soil seedbank concentrations were highest at the 0-5 cm depth of October-planted wheat, which had nearly a 10-fold higher concentrations compared to safflower and September-planted wheat at this depth. There were no differences at depths below 5cm.

This study showed the use of safflower to be a very useful management tool for reducing jointed goatgrass populations. September-planted wheat, with similar jointed goatgrass populations, yielded higher, and had less contamination and was therefore more competitive with jointed goatgrass than wheat planted in October, observed through a reduction in jointed goatgrass propagule production. Planting wheat in October, for the purpose of controlling jointed goatgrass through additional tillage, proved ineffective. Jointed goatgrass population densities were not reduced in experiment one, and only slightly reduced in experiment two. The dramatic loss of yield, associated with the later plantings, far outweighs any benefits gained by delaying wheat planting.

(69 pages)

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INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is an important crop throughout the West and Great Plains of the U.S. At some locations, wheat is often the only crop grown. This is partially due to the arid and semiarid conditions of these regions that limit crop selection, and yet wheat serves as an important rotational crop in areas with adequate water supply. Combined with the adoption of extreme conservational farming methods over the past few decades, continuous wheat cropping has encouraged the spread and intensity of many winter annual grasses (Donald and Ogg 1991). Jointed goatgrass (*Aegilops cylindrica* Host.), a close relative of wheat, is one annual grass becoming particularly troublesome for winter wheat producers in the West (Donald 1991). Jointed goatgrass is estimated to infest nearly 2 million ha (5 million acres) of farmland, costing producers an estimated $35 million in reduced crop yields annually. Total annual economic losses due to jointed goatgrass exceed $145 million in reduced crop yields, decreased crop values, increased control costs, and reduced farm values (Ogg 1993).

Jointed goatgrass is native to western Asia and eastern Europe. It was introduced to North America at multiple locations, most likely as a contaminant of imported wheat. The first recorded herbarium sample was collected in 1870 in Centerville, Delaware. It is speculated to have been introduced into Kansas during the late nineteenth century as a contaminant of 'Turkey' winter wheat brought from Russia by immigrants, and was first identified in Kansas in 1917. Other initial herbarium recordings include South Dakota in 1910, 1917 in Washington, and 1926 in Oregon (Donald and Ogg 1991). Many new infestations are now blamed on transportation of contaminated wheat in uncovered trucks, and railway cars, along with custom combine operations that move from areas of infestation to non-infested areas without cleaning their equipment. Although it is found throughout the continental United States, it has become a serious problem primarily in the winter wheat-fallow, non-irrigated growing regions of the western United States (Lyon 1997). In Utah, a 1993 survey showed jointed goatgrass infested over 21,000 ha (52,000 acres) of farmland. This costs Utah wheat-growers over $1 million in direct yield losses each year due to jointed goatgrass competition (Ogg 1993).

Because of the close genetic relationship between jointed goatgrass and wheat, herbicides are not currently available for selectively controlling jointed goatgrass in wheat. This weed can be controlled by herbicides in other crops, but most of these cannot be grown due to the low annual precipitation typical of areas with dense jointed goatgrass infestations. Wheat growers in these regions have had to rely primarily on cultural practices, such as crop rotation, tillage, fertilizer placement, delayed planting, and the use of taller, more competitive wheat varieties for jointed goatgrass control.

Safflower, a spring-planted crop, has recently been introduced as a rotational dryland crop for farmers in northern Utah. Using spring crops allows tillage along with the use of selective herbicides for controlling jointed goatgrass as well as other annual weeds. What effect this has on long-term weed populations has not been thoroughly studied. It is generally agreed that use of spring crops should have positive results in reducing weed populations, especially from winter annual weeds such as jointed goatgrass.

Jointed goatgrass is well adapted to the stubble-mulch conservation tillage methods used by many growers throughout the Great Plains and the West for controlling soil erosion (Donald 1984). Jointed goatgrass seeds do not require incorporation into the soil to germinate. One study revealed that 96% of jointed goatgrass seeds would germinate and establish if left on the soil surface, while downy brome (*Bromus tectorum* L.) and wheat germinated and established at rates near 30 % (Donald and Ogg 1991). The use of surface tillage equipment, such as rodweeders, or light disks, could effectively eliminate most surface germinating jointed goatgrass seedlings.

The adoption of conservational farming practices over the past 20 yr has been accompanied by an increase of many annual grassy weeds, such as jointed goatgrass and downy brome. Whether this is coincidental or a result of the agronomic practices accompanying these alternative-cropping systems has not been determined. However, a 1988 survey in Montana indicated that jointed goatgrass was more frequently a problem on farms using conservation tillage than on farms using conventional tillage methods (Donald and Ogg 1991). Conservational methods of farming have proven to decrease soil losses, but many fields experience increased weed problems. Complete abandonment of conservative farming methods is not necessary as long as alterations can be made for controlling new problem weeds.

Delayed planting dates for small grains have been suggested as a way of helping reduce winter annual weed pressure (Miller and Whiston, 1995). Jointed goatgrass field germination occurs in early fall after temperatures drop, and soil moisture increases with fall precipitation. Winter wheat is generally planted at this time also. By delaying wheat planting a few weeks it is proposed that many jointed goatgrass seedlings could be eliminated through preplant tillage. What effect this truly has on jointed goatgrass population has not been concluded.

A 5-yr study using spring crop rotation, delayed planting, and different tillage levels for controlling jointed goatgrass was initiated September 24, 1996 in Box Elder County, Utah, with a replicate of this study at the same site initiated September 15, 1997. These experiments compare two tillage practices (conservation and conventional), three different 5-yr crop rotations (two of which include a safflower spring crop), and a September and an October planting date for wheat. Effects of the different treatments were determined by counting number of jointed goatgrass plants in each plot, the percent contamination of harvested seed (grain contamination), and wheat yield, and through measuring soil seedbank reserves.

Two different tillage regimes (conservational and conventional) were used in the experiments. Conservational tillage included fall ripping, which allows winter moisture infiltration but leaves most crop residues on the soil surface. Only one spring tillage cultivation was made to destroy weeds during the fallow season so that surface residue levels would be in compliance with existing federal soil conservation farm programs. Conventional tillage also includes fall ripping, but fallow season tillage was more vigorous, and was not concerned with leaving sufficient crop residues on the soil surface to meet crop residue compliance levels.

Both experiments were set up as 5-yr studies. Results from the first 2 years will be examined in this report. Only the initial effects of some treatments will be examined; further studies by others will be necessary to determine the final outcome. A 5-yr rotation is a necessary component of this study and is vital for examining the long-term effects each of these treatments has upon the population of jointed goatgrass in their respective plots. Again, only the initial stages of this experiment will be reported in this thesis. The effects of planting date and crop planted will be compared for their effects on jointed goatgrass population and seedbank reserve, along with crop production. Because tillage practices are only in fallow years, no differences in tillage practice will have occurred prior to the termination of this thesis. No results dealing with different tillage practices will be reported in this paper.

OBJECTIVES

To compare different crop management practices, crop rotation, and planting date for:

1. Population and seed production of jointed goatgrass
2. Jointed goatgrass soil seedbank effects
3. Wheat and safflower yield
4. Percent contamination of wheat and safflower by jointed goatgrass spikelets.

LITERATURE REVIEW

Economic Impact

Jointed goatgrass (*Aegilops cylindrica* Host.) has become a very serious threat to winter wheat (*Triticum aestivum* L.) growers in the Southern Plains, Great Plains and Pacific Northwest of the United States (Fleming et al. 1988). A 1993 survey showed jointed goatgrass infestations on nearly 5 million cropland acres in 14 western states (Ogg 1993), and found it to be spreading at a rate of nearly 50,000 acres per year (Dewey 1996). An infestation of around 50 plants m^{-2} has been reported to reduce winter wheat yields by 25% (Fleming et al. 1988). In addition to yield losses, growers can also be penalized when marketing their jointed goatgrass contaminated grain through a percent dockage on the amount they are paid per bushel (Larson 1997). In Wyoming, it is estimated that jointed goatgrass reduces the amount that growers are paid for their wheat by an average of 15% or more (Miller and Whiston 1995). Yield losses, along with decreased crop values (due to weed seed contamination), increased costs of weed control, and reduced farm values (as a result of jointed goatgrass infestations) cost wheat growers an estimated $145 million annually (Ogg 1993).

Biology

The biological description of jointed goatgrass is important in showing how it has filled a niche in the dry-land winter wheat production areas of the West, especially in areas practicing minimum and no-till soil conservation farming practices. Certain biological similarities between jointed goatgrass and winter wheat have allowed this weed to become a very competitive weed problem for growers throughout the West.

Plant Description

Jointed goatgrass is a winter annual grass native to western Asia and eastern Europe. Two varieties of jointed goatgrass (*rubiginosa* and *cylindrica*) are common. Variety *rubiginosa* has pubescent outer glumes on the spikelets, while spikelets of variety *cylindrica* are glabrous to scabrous (Donald and Ogg 1991).

Jointed goatgrass leaves are alternate, 3 to 6 mm wide, and 5 to 12 cm long. Plant height varies from 40 to 60 cm. Auricles, leaf sheaths, and blades are hairy. The leaf margins are lined with obvious, finely divided, evenly spaced hairs. The seedhead is a spike, 5 to 10 cm long, that abscises between the non-dehiscent spikelets along the rachis, with a segment of the rachis remaining attached to each spikelet (Donald and Ogg 1991; Miller and Whiston 1995). There are generally 5 to 10 spikelets per spike (Lyon 1997). Spikelets are 8 to 10 mm long, remain intact, and normally contain 1 to 2 seeds, with 3 seeds developing occasionally. Glumes are either awnless or have one awn that varies in length from 3 to 9 mm, and only the glumes of the uppermost spikelets have long awns. Seeds of jointed goatgrass are reddish-brown, grooved, 6.5 to 9 mm long, and 2 mm wide. Seeds adhere to the lemma and palea, along with the glumes and rachis, making them difficult to remove from the spikelet. Seeds germinate and grow while still inside the spikelet (Donald and Ogg 1991). Jointed goatgrass can produce up to 135 tillers, 100 spikes, 1,500 spikelets, and 3,000 seeds on a single plant, although it generally produces a lot fewer when competing with wheat (Lyon 1997).

Genetics

Jointed goatgrass is genetically related to wheat. Jointed goatgrass is an allotetraploid (4 genomes) containing 28 chromosomes. Each genome contains 7 chromosomes obtained from two parent species. These genomes are identified as CC and DD. Wheat is an allohexaploid (6 genomes) with 42 chromosomes from three parent species. Wheat genomes are AA, BB, and DD. The DD genomes in wheat and jointed goatgrass are nearly identical, which allows occasional hybrid crosses between the two species. The resulting hybrid is nearly always sterile (95% or greater), although fertile offspring have been produced from hybrids in greenhouse studies (Zemetra et al. 1996). Manipulation of wheat genetics to confer herbicide resistance could result in passing this resistance to jointed goatgrass. Herbicide-resistant jointed goatgrass could pose an even greater threat to winter wheat production. Even so, imidazolinone and glyphosate-resistant biotypes of wheat are currently being introduced.

Competition with Wheat

Jointed goatgrass is very competitive with wheat for plant growth resources. Jointed goatgrass and winter wheat have similar rooting depths (around 135cm), and therefore compete similarly for limited water and nutrients (Anderson 1993). A jointed goatgrass population of 18 plants m^{-2} reduced wheat yields by 27%, mostly due to reduced numbers of reproductive wheat tillers (Anderson 1993). Jointed goatgrass is more competitive to wheat when soil moisture is low. During periods of high soil moisture, wheat produces more dry matter than jointed goatgrass, but when soil moisture is low, jointed goatgrass is able to accumulate more dry matter than winter wheat.

Jointed goatgrass is also more competitive in warmer climates (Fleming et al. 1988).

Seed Characteristics and Regulations

Wheat and jointed goatgrass seeds have similar geometric and gravimetric properties. These similarities make jointed goatgrass spikelets very difficult to remove from wheat through normal cleaning processes. This difficulty has caused many states to adopt strict laws in regulating seed of this weed.

Laws and Restrictions

Jointed goatgrass spikelets and wheat seeds have very similar cross-sectional diameters, and specific gravities. For this reason it has proven very difficult to remove jointed goatgrass seeds from contaminated wheat during normal milling, and cleaning processes (Herron 1996). Indent cylinders, and gravity tables can remove most jointed goatgrass spikelets from wheat, but no cleaning process has proven completely effective (Karow et al. 1996). Therefore, many states have a zero tolerance for jointed goatgrass in certified wheat. This means that if even one jointed goatgrass spikelet is found in a sample of seed, it cannot be sold as certified seed (Larson 1997). In 1990, Idaho and Washington adopted even stricter laws against jointed goatgrass. Any field containing jointed goatgrass is ineligible for certified wheat production until a rigorous reclamation program is completed. In Washington, this is a 5-yr program on dryland or a 3-yr program on irrigated cropland. During this time, certified wheat cannot be grown, yearly field inspections are conducted during the rehabilitation period and a minimum of three inspections are conducted in the first year of seed production following the rehabilitation process. If, during any inspection, jointed goatgrass plants are found, the rehabilitation program is determined unsuccessful, and the grower must start over from the beginning. To date, no field removed from seed production, due to jointed goatgrass, has been reclaimed (Goemmer 1996).

Dormancy

Jointed goatgrass has been shown to exhibit type III seed reserve behavior, an intermediate type of persistence where the majority of seeds germinate early, while the remainder persist for several years (Donald 1991; Lyon 1997). At harvest, jointed goatgrass seeds are 100% dormant. After one month of storage, jointed goatgrass germination rates are between 50 and 75% (Donald 1991). An experiment by Donald and Zimdahl (1987) in Colorado showed that most of the jointed goatgrass seeds buried 5 cm deep in the soil were lost within 3 yr due to germination or degradation. In areas with lower precipitation, seed dormancy may last even longer. This is due to lower rates of germination, and slowed seed decay (Lyon 1997). Jointed goatgrass seeds stored under dry conditions can remain viable for many years. Spikelets used for plantings in our experiments were at least 7 yr old and germination rates remained above 90%.

The tetrazolium assay is a commonly used method for estimating the viability of seeds, and can be used with jointed goatgrass (Donald 1994). This method requires the removal of the caryopsis from the spikelet before the test can be conducted, making it difficult to test large quantities of seeds. It also fails to show whether or not the seed is dormant, and cannot measure seed vigor. The mechanisms for seed dormancy in jointed goatgrass have not been studied thoroughly and are unknown. One possible method for dormancy is chemical germination inhibitors, such as abscisic acid, present in the pericarp or testa, such as is the case with the wheats, *Aegilops kotschyi* and *Aegilops ovata*, all of which are close relatives of jointed goatgrass (Bewley and Black 1994; Donald and Ogg 1991; Morrow et al. 1982). The regulatory gene pBS 128 mRNA has been found to increase in concentration in hydrated dormant seeds of jointed goatgrass, along with cheat (*Bromus secalinus*), downy brome, common rye (*Secale cereale*), wild oat (*Avena fatua*), and red rice (*Oryza sativa*). In hydrated nondormant seeds, the level of this mRNA decreased over time after initiation of imbibition, and was undetectable after 6 h. How this gene affects dormancy of these plants is unclear. It is known to be down-regulated by gibberellic acid, a germination promoter, and is promoted by abscisic acid, a germination inhibitor (Walker-Simmons and Goldmark 1996). Determining the mechanisms responsible for seed dormancy in jointed goatgrass would be helpful in understanding its role in the proliferation of this weedy species.

Control

Cultural practices are currently the primary method used for jointed goatgrass control. Cultural weed control includes crop rotation, mowing stands of goatgrass in noncropped areas such as roadsides or field borders before seeds are produced, removing all seeds possible during harvest by cutting low, proper fertilizer placement, and burning wheat stubble (Willis et al. 1989; Young et al. 1990). Non-selective herbicides are also used to control jointed goatgrass during fallow periods or in noncropped areas (Donald and Ogg 1991). The best way to deal with jointed goatgrass is to avoid getting it, through preventative measures such as the use of certified noxious-weed-free seed, cleaning combines before they are moved from one field to another, and monitoring field borders.

Even though these sound like simple options, studies report that only half of the growers in Oregon and Idaho actually use certified wheat (Trebon 1996), mainly due to the increased costs of purchasing certified seed. An extensive drill box survey in Utah also revealed jointed goatgrass contamination in 6% of 450 grain samples, showing that farmers were either knowingly or unknowingly spreading the problem by actually planting more jointed goatgrass into their own fields (Ogg 1993). Custom combine operations have also been blamed for the extensive areas of infestation throughout the Great Plains states. The mandatory tarping of all farm trucks carrying wheat or other grains has been suggested as a means of slowing the spread. Because jointed goatgrass has lower seed density than wheat, it naturally sifts to the top of grain loads where it can be blown off and contaminate roadsides, fields, and other locations, eventually resulting in new infestations (Larson 1997; Miller and Whiston 1995).

Crop Rotation and Management

Crop rotation and management have played a vital role in deterring the spread of weeds. Using an integrated approach, rather than relying on one method alone (such as herbicides), allows for the greatest spectrum of weed control. Integrated management, including tillage, timing of planting, fertilization, crop rotation, and herbicides, combines to put pressure on weeds and increase crop production. Few crop management strategies have been studied in depth on jointed goatgrass. Crop rotations that include a spring crop have been suggested as a way for reducing stands of jointed goatgrass, but there is little supporting research to validate this claim (Donald and Ogg 1991; Lyon 1993).

Jointed goatgrass is a winter annual plant that has a facultative vernalization requirement. Donald (1994) in Colorado studied jointed goatgrass seed vernalization requirements and found that unvernalized jointed goatgrass seedlings require 7 to 8 months to begin flowering. By rotating to a spring crop, all vernalized seedlings can be eliminated through tillage prior to crop planting, although some spring germinating jointed goatgrass may mature if spring temperatures are low enough (less than 3° C [37° F]) (Lyon 1997). This may reduce the number of jointed goatgrass the following season by reducing the number of seeds returned to the soil seedbank.

In many western states, crop rotations are minimal because of the typically arid or semiarid conditions. Conventional crop rotations include wheat one year followed by a fallow year, which is followed by wheat again, or continuous wheat without a fallow season in areas with adequate precipitation. This does not allow satisfactory control of jointed goatgrass (Lyon 1997). By including a spring crop in the rotation such as barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), sunflower (*Helianthus annuus* L.), millet (*Panicum* sp.), safflower (*Carthamus tinctorius* L.), or spring wheat, jointed goatgrass can be controlled more effectively (Donald and Ogg 1991; Miller and Whiston 1995). Not only does the inclusion of a spring crop eliminate fall-germinating jointed goatgrass seedlings by tillage, but some of these crops also allow the use of selective herbicides to control jointed goatgrass seeds that germinate in the spring.

Delay of Planting

Delaying planting of wheat until the last recommended date for planting is also a suggested way to reduce jointed goatgrass infestations (Miller and Whiston 1995). Jointed goatgrass germinates in mid-to-late fall. Delaying wheat planting allows for tillage or nonselective herbicides to remove jointed goatgrass seedlings before planting. Including tillage or herbicides directly before planting kills most jointed goatgrass seedlings that have emerged, and gives the wheat a competitive advantage for plant growth resources.

Planting earlier may also have an advantage in that it would allow the wheat to mature more during the fall, making it more competitive with the jointed goatgrass that does emerge. Anderson (1993) showed that jointed goatgrass that emerged 14 d after wheat emergence produced 36% less spikelets. If wheat was able to emerge and grow prior to jointed goatgrass, it would have a competitive advantage for resources (such as water, nutrients, and sunlight). Blue et al. (1990) and Winter and Musick (1993), have also shown that wheat yields are maximized when wheat is planted at a date which allows approximately 400 growing degree days (GDD, 4.4° C base temperature) between planting and December 31. These yields are correlated to the depth and timing of water extraction from the soil. Planting too early removes too much water in the fall leaving too little for spring growth and seed production. Planting too late results in reduced depth of rooting and total water extraction (Winter and Musick 1993).

Tillage

Jointed goatgrass is well adapted to stubble-mulch conservation tillage methods used by many growers throughout the Central Great Plains and the West for controlling soil erosion (Donald 1984), because seeds do not require incorporation into the soil to germinate. One study revealed that 96% of jointed goatgrass seeds germinated and established when left on the soil surface, while downy brome and wheat germinated and established at rates of around 30% (Donald and Ogg 1991). The use of surface tillage equipment, such as rodweeders, or light disks, could effectively eliminate most of these seedlings. Conservation tillage and farming practices have increased greatly in the past 20 yr; concomitantly, jointed goatgrass and other annual grassy weeds have become increasingly troublesome. Most conservation farming methods are integral to soil conservation plans, and may be federally mandated for farmers participating in federal farm subsidy programs. A 1988 Montana survey indicated that jointed goatgrass was more frequently a problem on farms using conservation tillage than on farms using conventional tillage methods (Donald and Ogg 1991). Although conservational methods of farming have proven to decrease soil erosion losses, they have increased weed problems. Changing tillage practices is not necessary as long as other weed control options are available to control new problem weeds.

Herbicides

The use of herbicides in controlling jointed goatgrass in wheat is very limited. This is mainly because the herbicides that control jointed goatgrass also have damaging effects on wheat. The introduction of transgenic crops, including imadazolinone, and glyphosate-resistant wheat varieties, may help in the control of this weed. Currently, herbicides, along with tillage, play a vital role only in the fallow season of the wheat-fallow crop rotation for reducing jointed goatgrass populations (Donald 1991).

MATERIALS AND METHODS

Experimental Design

This investigation was designed to compare crop rotation, tillage practice, and planting date for jointed goatgrass control in a winter wheat-fallow cropping regime typical of the Intermountain region. Two experiments were established in Northern Utah with essentially identical treatments. Experiment one was initiated in the fall of 1996 and Experiment two was initiated a year later in 1997. The experimental design was the same for both experiments and consisted of a randomized block design with split plots. Each whole plot was assigned a type of tillage practice and a planting date (early or late). Whole plots were divided into three subplots, and each was randomly assigned one crop rotation. Each whole plot contains all three crop rotations. Three repetitions were used for each treatment. Each repetition was blocked so that each treatment would fall within the geographical area assigned for each repetition. Whole plots were randomly assigned to different locations within the blocked local controls. For this paper, only the different planting dates and the first year crops of the crop rotations will be used for comparison, because tillage treatments will not begin until the summer of 1998, and crop rotations will last over a time period of 5 yr. Because no there were no differences in tillage or crop rotation, four replications of each treatment occurred in each block, for a total of 12 replications of each treatment in each of the two experiments. Soil samples taken in this experiment were split into three depths, and were analyzed as a split plot, with each depth being a subplot of each whole-plot treatment.

Plot Setup and Planting Procedures

In experiment one, plots were set up on a 9,200 m^2 (2.27 acre) rectangular field measuring 137.2 by 67.1 m (450 by 220 ft) on the Utah State University Blue Creek research farm in Box Elder County, Utah. On September 24, 1996, this field was divided into thirty-six 0.0186 ha (0.0459 acre) plots measuring 7.6 by 30.5 m (25 by 100 ft). A 6.1 m (20 ft) border divided the upper plots from the lower plots in the field. The main purpose of this border was to serve as a tractor turning and travel space between plots. Experiment two was set up on an adjacent 8,736 m^2 (2.16 acre) quadrilateral field with the dimensions 140.5 by 137.2 by 76.3 by 45.8 m (461 by 450 by 250 by 150 ft) in the fall of 1997. Plot size was reduced to 7.6 by 24.4 m (25 by 80 ft) due limited available area and the odd dimensions of the field.

To achieve a fairly evenly distributed stand of jointed goatgrass, spikelets remaining from a previous experiment conducted at Utah State University were scattered using a hand-pushed broadcast fertilizer spreader on September 24, 1998 over all plots. Approximately 12.7 kg (28 lb) of jointed goatgrass spikelets was scattered onto experiment one. No jointed goatgrass seed was spread in the buffer zone. Jointed goatgrass spikelets from this source weighed 0.03g per spikelet. This seed was 77% pure jointed goatgrass spikelets with a germination rate of 92%.

Germination rates were verified by placing 25 jointed goatgrass spikelets into four petri dishes (100 spikelets total) with moistened filter paper, and sealed with parafilm®. Petri dishes were placed in a closed laboratory drawer and temperature was maintained near 21° C. Germination counts were taken at 1- and 2-week intervals. First-week spikelet germination rate was 92%. A spikelet was determined to have germinated if either the radicle or the coleoptile had visibly emerged. Since jointed goatgrass spikelets generally have more than one seed, spikelets germinating the first week were dissected to reveal number of seeds per spikelet and the percent germination of all seeds. Ungerminated seeds removed from germinated jointed goatgrass spikelets were returned to a petri dish for 1 week to measure additional germination. Spikelets failing to germinate the first week were left intact and placed in a petri dish for another week, and were then disected. No spikelets failing to germinate within 1 week germinated after a second week. Dissection of the spikelets showed that 90% had two seeds, 8% had one seed, and 2% had three seeds. Total seed germination after 2 weeks was 90.2%. Of the spikelets that had at least one seed that germinated the first week, 97.2% of the seeds were viable and germinated by week two (only 5 out of 180 seeds failed to germinate).

Multiplying the purity by the spikelet germination rate revealed 71% pure live seed (PLS), which is somewhat low, but expected because of the low purity of the seed source. The germination rate was a little higher than expected knowing that the seed was approximately 7 yr old. Multiplying PLS by seed weight spread provided the total viable seed weight used. Dividing this by the average weight of the jointed goatgrass spikelet results in the total number of spikelets that were scattered on the experiment. The final distribution of jointed goatgrass was 32.7 viable spikelets m^{-2} (Equation 1).

$$\text{Spikelets } m^{-2} = [((\text{PLS}) \times \text{Total Seed Weight}) \div \text{Average Seed Weight}] \div m^2 \quad \textbf{[1]}$$

After scattering the jointed goatgrass spikelets, a cultipacker was passed over the field to lightly incorporate the spikelets. 'Weston' wheat, a tall variety of wheat commonly grown in this area, was then planted (on September 24, 1998) in the early planting date blocks of experiment one using a deep furrow drill with 10-inch row spacing. Planting rate was 78.5 kg ha^{-1} (70 lb $acre^{-1}$). Experiment two was planted with 'Promontory' wheat due to a change in grower preference and the limited availability of 'Weston' wheat. 'Promontory' wheat will be used for all future plantings.

On October 18, 1996, the late planting date plots were prepared for planting using a rodweeder cultivator. The purpose of this tillage was to kill any weeds, including jointed goatgrass, that had emerged prior to planting. 'Weston' variety wheat was then planted in these plots as in the September plots; borders were also planted at this time. Both jointed goatgrass and wheat in the September plantings had emerged by mid-October. The wheat had 3 to 4 leaves and was 15 to 20 cm high. The jointed goatgrass had 2 to 3 leaves and was 7 to 10 cm high.

Plots to be planted to safflower were left untouched until the following spring. On April 18, all plots to be planted with safflower were sprayed with trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzamine], and tilled using a cultipacker, and an S-tine harrow. Trifluralin is a residual herbicide that is quite active on grass species, but does not injure safflower. This herbicide application was intended to reduce weed (including jointed goatgrass) emergence in the growing safflower. After the herbicide and tillage applications safflower (cultivar Tech 208) was planted at 19 kg ha^{-1} (17 lb $acre^{-1}$) using a deep furrow drill.

Experiment two was supplemented with jointed goatgrass from the same source used in experiment one to establish a base population. The early planting date plots were cultivated using a solid shank ripper-rodweeder combination, and were then planted on

September 15, 1997. The late planting date plots were tilled, using a ripper and a rodweeder, and planted on October 14, 1997. Wheat was planted at 78 kg ha^{-1} (70 lb $acre^{-1}$) as it was in experiment one. Wheat planted in September was beginning to tiller at this time. The jointed goatgrass had also emerged and was in the 3 to 4 leaf stage. Safflower was planted on May 4, 1998 after plots were treated with trifluralin and cultivated as previously in experiment one.

Soil Sampling

Measuring soil seed reserves is critical for observing changes in weed populations. Initial soil seed numbers will be compared with those recorded in resulting soil seed samples taken annually in each treatment.

On February 6, 1997, nine soil samples from frozen, snow-covered soil were taken from random locations throughout experiment one. Individual soil samples were not taken from each plot because all plots should have similar spikelet numbers at this point in the experiment. A 7.6-cm (3-inch) diameter soil sampler was driven into the soil 20.3 cm (8 inches) using a slide hammer. Samples were divided into the depth increments of 0 to 5 cm, 5 to 10 cm, and 10 to 20 cm. Each subsample was placed into a sealed bag for storage. Two weeks later, the soil samples were passed through a soil elutriator at the USDA-ARS/FRRL in Logan, Utah. A soil elutriator is capable of separating the lighter organic matter from the heavier soil particles. The organic fraction was captured in a fine mesh sieve, and sorted to count the number of jointed goatgrass spikelets present in each sample

On November 5, 1997, soil samples were taken on all plots of the initial experiment using a sampling shovel (Appendix 1, Tables 5, 6, and 7). Samples were taken at 0-5 cm, 5-10 cm, and 10-15 cm. Sample volume was 688 cm^3. Initial soil samples were taken from experiment two at this time at identical soil depths. These samples were elutriated on Jan 8, 1998.

Plant Counts

To estimate plant population densities, random plant counts were conducted using square meter quadrats. These plant counts measure the effects each treatment has on the population of jointed goatgrass.

On April 17, 1997, seedling jointed goatgrass plants were counted in experiment one by randomly placing a square meter quadrat in all plots that were to be planted with safflower, and counting any jointed goatgrass plants that fell within the quadrat. The purpose of these counts was to compare the initial number of jointed goatgrass prior to safflower planting, with the number of jointed goatgrass plants present later in the season after planting.

On May 8, jointed goatgrass plants were counted in all wheat plots of experiment one by randomly placing a square meter quadrat and counting seedlings therein (Appendix 1, Table 8). The delay in counting jointed goatgrass seedlings in wheat was to make counting easier, as seedlings were very small, and hard to differentiate from wheat seedlings. Wheat plants were starting to joint while the jointed goatgrass reamained in the tillering stage. Very few other weeds were present. The safflower had germinated and was in the two to four leaf stage.

On June 30, 1997, jointed goatgrass plants were counted in the safflower plots of experiment one. All plants in each plot were counted because of the low number of plants present (Appendix 1, Table 9). The purpose of this count was to measure changes in jointed goatgrass plant population when a spring crop (safflower) is used. At this point the jointed goatgrass and wheat were in spike and the safflower was pre-bloom.

On April 21, 1998, jointed goatgrass plants were counted within a randomly placed meter quadrat in fallow plots of experiment one, and in all plots of experiment two (Appendix 1, Tables 10, 11). On May 27, 1998, follow-up plant counts were taken in planted safflower plots of experiment two as in 1997 by counting all jointed goatgrass plants contained within individual plots (Appendix 1, Table 12).

Harvest

All wheat plots of experiment one were harvested on August 25, 1997 using a combine with a 2 m wide header. One 2-m wide swath was taken from each treatment for data collection, and the remainder was removed after all data collection had been finished. Total area harvested per plot for yield was 61 m^2. Weights were recorded with a data collector mounted on the combine (Appendix 1, Table 13). A subsample was taken from each plot to calculate dockage due to jointed goatgrass contamination (Appendix 1, Table 15). These subsamples were taken automatically with a sampler built into the combine. The sampler removes several small subsamples as a plot is harvested and combines them into one.

At harvest time, most jointed goatgrass spikes had partially disarticulated, leaving only the bottom two or three spikelets attached to the reproductive tiller. This is typical of jointed goatgrass, which generally matures before wheat. Because of this characteristic, it is often impossible to remove even a majority of the spikelets during harvest.

Safflower plots were harvested in experiment one nearly 1 month later on September 26, 1997. These plots were harvested with the same combine used to harvest wheat plots, and subsamples were also taken to show jointed goatgrass contamination (Appendix 1, Table 15). Yields were measured (Appendix 1, Table 13), but no comparisons could be made between the two crops (wheat and safflower) for this parameter.

Experiment two was harvested in the same manner as in experiment one. Wheat was harvested on August 24, 1998. Safflower was harvested on October 20, 1998 (Appendix 1, Table 14). Samples were taken in wheat for determining jointed goatgrass contamination (Appendix 1, Table 16). No samples were taken from safflower plots. However, it was observed that the harvested safflower contained virtually no jointed goatgrass. Safflower plots were heavily infested with grasshoppers during 1998, which resulted in decreased yields.

Tillage

All plots of experiment one were tilled on October 14, 1997 using a solid shank ripper. This type of tillage implement breaks up the soil surface without inverting the soil or removing much of the crop residues. The purpose of this tillage was to break the soil surface, allowing water to infiltrate more easily, while retaining adequate surface crop residue cover to slow erosion. The plots were tilled in an east to west direction. Plots of experiment two were tilled on October 25, 1998 as previously done in experiment one.

Statistical Analysis

Data were analyzed using ANOVA (analysis of variance) procedures using the SAS software. Effects of treatments on wheat yields, jointed goatgrass plant density, crop contamination, and soil seedbank concentrations for jointed goatgrass were analyzed for significant differences. Comparisons between first and second year plant counts were also analyzed. LSD (least significant difference) multiple means comparison tests were performed to reveal differences between treatments. Appendix 2 contains ANOVA tables for all treatments.

RESULTS

Visual Observations

Some anticipated visual differences were readily observed between the early planted wheat compared with wheat planted approximately 1 month later. Early planting provided for greater vegetative growth of the crop and rapidly closed the interrow spaces to limit the potential for weeds. Early planted wheat in both experiments had a noticeable advantage in that it had more time for growth in the fall through an increased number of growing degree days (GDD, 4° C base temperature). September-planted wheat received 322 GDD in 1996, and 438 GDD in 1997 between planting and December 31. October-planted wheat received only 103 GDD in 1996, and 160 GDD in 1997. This increased growth time period allowed for additional tillering in the fall and early spring, which filled the interrow spaces much earlier than the late-planted wheat. By April, in both experiments, wheat planted in September had multiple tillers while wheat planted in October had not begun to tiller, or had few tillers. The early-planted wheat also matured earlier than the late-planted wheat. By mid-to-late June the wheat planted in September had headed out, while wheat planted in October was still in the boot stage. This allowed the seeds to fill while moisture was still plentiful. This may explain some of the differences in yield and contamination between these two treatments.

Plant Counts

Initial counts of jointed goatgrass seedlings taken in the spring of 1997 showed no differences in populations between September-planted wheat, October-planted wheat, or in bare plots not yet planted to safflower (Table 1; Appendix 2, Table 19).

Table 1. Number of jointed goatgrass seedlings in safflower, September-planted wheat, and October-planted wheat in experiment one in 1997 and 1998, and experiment two in 1998.

Treatment	Seedling populations		
	1[a]-1997	1-1998	2-1998
	plants m^{-2}		
Safflower	0.342a[b]	-NA-	0.338a
Unplanted plots	9.8b	3.7a	9.5d
September wheat	11.1b	8.1ab	6.8c
October wheat	11.7b	14.9b	4.4b
LSD 0.05	3.0	5.1	1.5

[a]1 is experiment one, 2 is experiment two.
[b]Within columns, treatments followed by the same letter are not significantly different.

Average populations for these groups were 11.1, 11.7, and 9.8 plants m^{-2} respectively. Jointed goatgrass counts taken after planting safflower were reduced 96% compared with the average of the three groups just mentioned. Plant counts in these plots averaged 0.34 plants m^{-2} (Table 1; Appendix 2, Tables 17-20), a reduction attributed to spring tillage, and the use of the selective herbicide trifluralin.

Plant counts in the spring of 1998 during the fallow cycle of experiment one revealed similar jointed goatgrass population trends as previously mentioned. Fallow fields following the late planted wheat contained the highest levels of the weed at 14.9 plants m^{-2}, whereas fallow fields following early-planted wheat and safflower had 8.1 and 3.7 jointed goatgrass plants m^{-2}, respectively (Table 1; Appendix 2, Table 19). The number of jointed goatgrass was 55% less in fallow following safflower than in fallow following early-planted wheat, and 75% less than in fallow following late-planted wheat. Plant counts in fallow following early-planted wheat were 46% less than in fallow following late-planted wheat. Even with a fairly large difference between treatments, only fallow following safflower was significantly reduced when compared to fallow following October-planted wheat, with fallow following September-planted wheat not being significantly different from the other treatments. Combining jointed goatgrass population data over 1997 and 1998 for experiment one showed no significant difference between years, and showed similar differences between treatment (Appendix 2, Table 23).

In experiment two, late-planted wheat resulted in slightly reduced numbers of jointed goatgrass plants. The October-planted wheat had significantly lower numbers of jointed goatgrass than did the bare, unplanted plots, and wheat planted in September (Appendix 2, Table 19). Jointed goatgrass plant counts were 6.8, 4.4, and 9.5, respectively, for September-planted wheat, October-planted wheat, and unplanted plots (Table 1). Combing the data for both experiments showed no significant differences between the two and had similar results for differences among treatments (Appendix 2, Table 20).

Jointed goatgrass numbers in established safflower were again significantly reduced from those recorded prior to planting (Appendix 2, Table 17). The average number of jointed goatgrass plants dropped from 9.5 to 0.338 plants m^{-2}, a 96% reduction. This is strongly related to the 1997 plant counts taken in safflower plots in the initial experiment where plant counts were reduced from 9.8 to 0.342 plants m^{-2}, also a 96% population reduction (Table 1).

Wheat and Safflower Yield

Two wheat planting dates spaced approximately 1 month apart were used to compare wheat yield and jointed goatgrass control. Planting early is thought to give an advantage to wheat through earlier maturation, and increased fall tillering. Planting late gives an advantage to wheat by allowing a late tillage practice to remove any jointed goatgrass that had emerged up to that point. Wheat yield is determined by numerous factors including soil fertility, water availability, competition with weeds, etc. Delayed wheat planting by a few weeks was predicted to have little impact on wheat yield. However, delayed wheat planting resulted in a dramatic reduction of wheat yield, while having no effect on reducing jointed goatgrass populations, and resulted in increased contamination of jointed goatgrass spikelets in the harvested wheat.

Wheat harvested in 1997 had significantly higher yields in the September-planted wheat compared to October-planted wheat (Appendix 2, Table 17). September-planted wheat averaged 11 bu/A more than October-planted wheat with yields of 51.2 and 40.2 bu/A, respectively (Table 2). The increased yield of September-planted wheat is likely due to the observed increase in fall growth and earlier maturation due to increased numbers of GDD in the fall, which decreased the competitiveness of jointed goatgrass, and increased the overall growth of wheat. Actual numbers of wheat and jointed goatgrass tillers were not measured as part of this experiment, but visual observations showed distinct differences between the two crop planting dates. This trend was also observed in the jointed goatgrass contamination of harvested wheat.

Wheat harvested from experiment two in 1998 showed similar yield results as experiment one in 1997, although there were significant increases in yield for both early- and late-planted wheat (Appendix 2, Table 22). There was also a significant difference in the interaction between year by treatment. These differences are most likely due to yearly variations in climate resulting in higher yields for both treatments. Wheat harvested from September-planted wheat averaged 76.7 bu/A, while wheat harvested from October-planted wheat averaged 50.2 bu/A, a difference of 26.5 bu/A. Again these differences in yield are most likely related to the number of GDD in the fall after planting. September-planted wheat received 438 GDD while October-planted wheat received only 160 GDD before December 31. The lower productivity of the later-planted wheat again resulted in a higher concentration of jointed goatgrass spikelets in the harvested wheat, although not to the same extent it did in 1997.

Safflower harvested from experiment one in 1997 averaged 20 bu/A (Table 2). No comparisons between wheat and safflower yields can be made due to differences in crops. However, comparisons of crop contamination were made, although these comparisons favor wheat over safflower due to lower yields typical of safflower.

Table 2. Wheat and safflower yield, and crop contamination for 1997, and 1998.

	Yield		Crop contamination	
Treatment	1[a]-1997	2-1998	1-1997	2-1998
	bu/A		g/kg[b]	
Safflower	20.0	6.9	0.64a	0[c]
September wheat	51.3a	76.7a	0.54a	24.5a
October wheat	40.2b	50.2b	2.37b	38.5b
LSD 0.05	3.74	13.7	0.63	5.4

[a]1 is experiment one, 2 is experiment two.
[b] g jointed goatgrass per kg wheat or safflower.
[c]No safflower contamination data was collected in 1998; therefore, analysis was not possible.

Safflower harvested from experiment two in 1998 yielded 6.9 bu/A (Table 2). This was considerably less than in 1997, and may be partially explained by a dense grasshopper infestation that denuded much of the safflower prior to maturity. Again no comparisons in yield can be made between safflower and wheat.

Crop Contamination

A dramatic contrast between early- and late-planted wheat existed regarding jointed goatgrass spikelet contamination of the harvested crop. It was thought that the similarities of jointed goatgrass populations in the two wheat crops would result in a similar contamination of the harvested crop. However, jointed goatgrass spikelet concentration (g of jointed goatgrass spikelets per kg harvested grain) in the October-planted wheat was more than four times greater than jointed goatgrass spikelet concentrations between safflower and the September-planted wheat. There were no significant difference between safflower and the September-planted wheat. The measured values for jointed goatgrass concentrations were 0.54, 2.37, and 0.64 g kg^{-1} (g jointed goatgrass spikelets per kg harvested grain) for September-planted wheat, October-planted wheat, and safflower, respectively (Table 2). These differences were significant when comparing October-planted wheat with safflower or September-planted wheat (Appendix 2; Table 18).

In experiment two, 1998 crop contamination was much greater than in experiment one in 1997. Jointed goatgrass spikelet concentrations in September-planted wheat, October-planted wheat, and safflower averaged 24.5 g kg^{-1}, 38.5 g kg^{-1}, and 0 g kg^{-1}, respectively (Table 1). Although no samples were taken for safflower contamination in 1998, it was observed that the harvested crop was virtually free of jointed goatgrass.

Safflower and wheat differ greatly in yield and seed density. This causes any comparison of the contamination of crop using g of jointed goatgrass spikelets per kg harvested crop to unfairly describe safflower contamination when compared to wheat contamination. To more fairly compare these two crops, the unit mg jointed goatgrass spikelets in the harvested crop per area harvested (m^2) were derived using equation 2.

$$\text{mg m}^{-2} = (\text{mg jointed goatgrass per kg crop}) \times (\text{kg crop per m}^2 \text{ harvested}) \qquad \textbf{[2]}$$

From this formula, jointed goatgrass contamination was determined for all treatments. Jointed goatgrass contamination was 185.5, 638.3, and 62.4 mg m^{-2} for September-planted wheat, October-planted wheat, and safflower, respectively. Using this formula, September-planted wheat had nearly three times the jointed goatgrass contamination of safflower. In 1998, jointed goatgrass contamination was calculated to be 12,028, 12,456, and 0 mg kg^{-1} for September-planted wheat, October-planted wheat, and safflower, respectively. Using this formula, October- and September-planted wheat had similar values in 1998. This is because the percent differences in yield and jointed goatgrass contamination (as g kg^{-1}) were very similar in 1998.

Soil Seedbank Dynamics

Measuring the quantity of weed seed in the soil can help in predicting future weed populations. The seed contained within the soil are called the soil seedbank, which refers to the amount of seed reserves a certain species has in the soil. These measurements somewhat reflect the degree of weed control for a given species. A weed that has been controlled well will have a low soil seedbank reserve, while weeds that have been allowed to proliferate will have high soil seedbank reserves. Soil seedbank measurements were taken initially, and in the fall, following tillage.

Initial baseline seed levels taken in February 1997 for experiment one showed a presence of jointed goatgrass seed within the soil. At the 0 to 5 cm depth, an average of 0.44 spikelets was found in each 226.7 cm^3 sample. This number of spikelets would average 1.94×10^{-3} per cm^3 of soil, or 95.8 spikelets m^{-2} to a depth of 5 cm (Equations 3 and 4; Table 3).

$$\text{Spikelets m}^{-3} = \text{Average Spikelet Count per Sample} \div \text{Volume of sample (m}^3\text{)} \quad \textbf{[3]}$$

$$\text{Spikelets m}^{-2} = \text{Spikelets m}^{-3} \times \text{Depth of Sample (m)} \quad \textbf{[4]}$$

To a depth of 5 to 10 cm, an average of 0.33 spikelets was found. This equates to 1.47×10^{-3} spikelets cm^{-3} of soil, which is 71.9 spikelets m^{-2} from depths of 5 to 10 cm. There were no spikelets found in samples below 10 cm (Table 3).

Baseline samples from experiment two taken in November 1997 showed an average of 0.09 spikelets per sample at depths of 0-5cm. This equated to an average of 19.9 spikelets per m^2. No spikelets were found in samples taken from depths below 5 cm (Table 3).

Soil seedbank measurements were taken again in the fall after tillage applications.

Table 3. Initial jointed goatgrass soil seedbank counts in February 1997, and January 1998 elutriated soil samples[a].

	1997-1	1998-2	1997-1	1998-2
Depth (cm)	spikelets per sample		spikelets per m^2	
0-5	0.44	0.09	97.0	19.9
5-10	0.33	0	72.8	0
10-20	0	0	0	0

[a]Samples were taken on February 6, 1997 and November 5, 1997.

This tillage allowed some of the jointed goatgrass spikelets that had disseminated onto the surface of the soil to be mixed within the soil. Seed concentrations were measured at 0-5 cm, 5-10 cm, and 10-15 cm. As expected, seed concentration decreased with soil depth for all treatments. October-planted wheat showed the least amount of control, and safflower showed the highest control levels. Plots planted to wheat in October had more than five times as many jointed goatgrass spikelets as did the plots where wheat was planted in September, and more than 15 times the levels found in plots planted with safflower. Differences were not significant at depths below 5 cm. However, there were no significant differences between the safflower and the September-planted wheat (Figure 1).

Even with the mixing of soil by tillage, all samples had higher levels of jointed goatgrass spikelets at the 0-5 cm level. At this depth, the numbers of spikelets were 9.8, 1.7, and 0.56 spikelets per sample in October-planted wheat, September-planted wheat, and safflower plots, respectively (Table 4). These differences were significant for September-planted wheat and safflower when compared to the October planting (Appendix 2, Table 21).

At 5-10 cm depths there were 1.8, 0.92, and 0.17 spikelets per sample in October-planted wheat, September-planted wheat, and safflower plots, respectively (Table 4). No differences were significant at this depth. At depths of 10-15 cm, October-planted wheat, September-planted wheat, and safflower plots contained 0.42, 0.67, and 0 spikelets per sample, respectively (Table 4). Again there were no significant differences at this depth. Differences in depth were significant; however, the only difference was between the 0-5 cm depth (9.8 spikelets) and the 5-10 cm depth (1.8 spikelets) in the October planting

(Table 4; Appendix 2, Table 21).

Soil sample volume was 688 cm^3 (42 in^3). By using equation 1, the numbers of spikelets m^{-2} were calculated. At the 0-5 cm depth there were 714, 121, and 42.4 spikelets m^{-2}, respectively, in October-planted wheat, September-planted wheat, and safflower. At the 5-10 cm depth there were 127, 66.6, and 12.1 spikelets m^{-2}, respectively, as before. At the 10-15 cm depth there were 30.3, 48.5, and 0.0 spikelets m^{-2}, respectively (Table 4). Comparing these concentrations to those taken initially, there was an increase at all depths for October-planted wheat, an increase at the 0-5 cm and 10-15 cm depths for September-planted wheat, and decreased or no changes in concentrations in safflower (Figure 1).

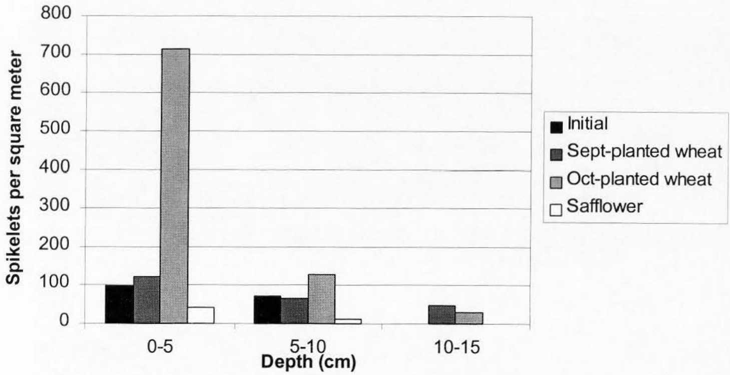

Figure 1. Number of jointed goatgrass spikelets per square meter in soil samples taken initially in all plots, and after one-year treatments of September-planted wheat, October-planted wheat, and safflower at soil depths of 0-5, 5-10, and 10-15 cm in experiment one.

Table 4. Number of jointed goatgrass spikelets per soil sample and estimated soil concentrations as spikelets per m^2 for October-planted wheat, September-planted wheat, and safflower in 1997 in experiment one.

	—Depth (cm)—				—Depth (cm)—		
Treatment	0-5	5-10	10-15	LSD 0.05	0-5	5-10	15-20
	—spikelets/sample—				—spikelets m^{-2}—		
October wheat	9.8aA[a]	1.8B	0.42B	2.0	714	127	30.3
September wheat	1.7b	0.92	0.67	NS	121	66.6	48.5
Safflower	0.58b	0.17	0	NS	42.4	12.1	0
LSD 0.05	1.96	NS	NS	---	--	--	--

[a]Within columns, treatments followed by the same lower case letter are not significantly different, within rows, depths followed by the same upper case letter are not significantly different. Soil samples were taken at 0-5, 5-10, and 10-15 cm on November 5, 1997.

CONCLUSIONS

Several conclusions can be made from the results obtained during the first 2 yr of these 5-yr experiments. Results show significant decreases in jointed goatgrass populations in safflower compared to unplanted plots and both winter wheat treatments. There was a 96% reduction in the jointed goatgrass population in safflower plots when comparing plant counts taken before and after planting. Jointed goatgrass seedlings were removed through preplant tillage, and the use of the herbicide trifluralin. From this we can conclude that the use of spring crops is helpful in reducing jointed goatgrass populations through removal of this weed prior to reproduction. This reduces the number of jointed goatgrass propagules in the soil in following years. The use of a residual herbicide, such as trifluralin, may also be beneficial in reducing jointed goatgrass emergence during fallow seasons. This agrees with findings of Westra and Stump (1995), who reported a 90% reduction in emergence of jointed goatgrass when a 3-yr spring crop fallow rotation was used compared to a wheat-fallow rotation. Complete elimination of jointed goatgrass was not achieved with a 1-yr spring crop rotation. Donald and Zimdahl (1987) showed that jointed goatgrass seed could remain viable in the soil for more than 5 yr, but most jointed goatgrass seed were lost within 3 yr due to germination or degradation. The reduction of jointed goatgrass propagules being returned to the soil when using a spring crop should prove beneficial in reducing jointed goatgrass populations in following years.

In 1998 in experiment two there were significant differences in numbers of jointed goatgrass plants counted in the different treatment. Plant counts were 55% less in the fallow following safflower than in fallow following September-planted wheat, and were 75% less than fallow following October-planted wheat. Plant counts in fallow following September-planted wheat were 46% less than fallow following October-planted wheat. However, differences were only significant when comparing fallow following safflower and fallow following October-planted wheat. Although jointed goatgrass was not completely eliminated from the safflower plots, the numbers of plants m^{-2} was only a third of that found in the previous year. These results also suggest that planting wheat in October would eventually increase jointed goatgrass populations even more than planting in September. This disagrees with the suggestions of Miller and Whiston (1995) who stated that delaying planting of winter wheat helps to control jointed goatgrass.

The two winter wheat crops differed in yield and jointed goatgrass contamination when early wheat planting (September 24 in 1996 and Septmeber 15 in 1997) was compared with late winter wheat planting (October 18 in 1996 and October 14 in 1997). September-planted wheat yielded an average of 11 bu/A more (25% higher) than October plantings in 1997 (experiment one), and 26.5 bu/acre more (35% higher) than October-planted wheat in 1998 (experiment two).

Even though jointed goatgrass seedling populations were similar in the two winter wheat crops (early vs late), contamination of harvested wheat was more than three times greater in October plantings in 1997, and 36% greater in 1998. The increase in jointed goatgrass contamination between years is not easily explained, and may be due to different harvesting procedures. Although the differences between years are quite different in both total yield and jointed goatgrass contamination, it is obvious that planting wheat later will not reduce jointed goatgrass populations, but will only result in decreased yields and greater dockage penalties when marketed. From experiment one in 1997 it appeared that planting earlier was reducing the total amount of jointed goatgrass seed being produced as jointed goatgrass concentration was 77% less in harvested wheat planted in September than that planted in October. This was not as apparent in experiment two in 1998 where differences in contamination were not as great, and could be explained almost entirely by differences in yield. This adds to the necessity of using a spring crop rotation to help in the control of this troublesome weed.

First-year results in both experiments showed that early plantings of wheat are more capable of controlling jointed goatgrass seed production and produce greater wheat yields, probably because of increased tillering, depth of rooting, and fall growth, which make it more competitive in reducing jointed goatgrass growth and reproduction. While results of experiment two in 1998 differed in the degree of control September-planted wheat had on reducing jointed goatgrass production, the differences in yields favored September planting even more. This is supported by Blue et al. (1990), who showed that wheat yield was optimal when receiving approximately 400 GDD between planting and the end of the year. In 1996, September-planted wheat received 322 GDD while the October-planted wheat received only 103 GDD. In the replicate experiment, there were 438 GDD between planting and December 31, 1997 for September plantings, while October plantings received only 160 GDD. September-planted wheat appeared more vigorous than the October planted wheat during spring jointed goatgrass plant counts. Wheat receiving approximately 400 GDD would be more competitive with jointed goatgrass through increases in tillering, quicker filling of inter-row spaces, and increased water extraction reducing the reproductive capabilities of this weed. Blue et al. (1990), showed that the delay of planting reduced numbers of reproductive spikes, which seemed to be the contributing factor to decreased yields. Winter and Musick (1993) showed a decrease in the depth of water extraction, and total water extraction when planting was delayed. They also showed that optimal yields were achieved when around 400 GDD were received prior to December 31. The increased yields were attributed mainly to the increase in number of reproductive tillers m^{-2}. Although optimal planting dates will not eliminate jointed goatgrass, they do make wheat more competitive, thus reducing jointed goatgrass seed production.

Safflower demonstrated to be a very promising alternative crop, particularly when combined with a selective herbicide like trifluralin. Safflower did not completely eliminate jointed goatgrass with just one year as a crop rotation, but did reduce it to less economically damaging levels. These reductions should prove very beneficial in preventing yield and dockage losses in future seasons.

Long-term effects of a 1-yr spring crop rotation, time of planting, and differences in conventional and conservation tillage on jointed goatgrass populations will be determined as a conclusion to this 5-yr study. At this point in the study it is hypothesized that jointed goatgrass populations will be lower in rotations that include a safflower crop, have conventional tillage, and are planted earlier. But none of these hypotheses can be proven conclusively at this point in the experiment due to the early stage of this experiment (the first and second years of two 5-yr rotations).

LITERATURE CITED

Anderson, R. L. 1993. Jointed goatgrass (*Aegilops cylindrica*) ecology and interference in winter wheat. Weed Sci. 41:388-393.

Bewley, J. D. and M. Black. 1994. Dormancy and control of germination. Pages 199-267 *in* J. D. Bewely and M. Black, eds. Seeds: Physiology of Development and Germination. 2nd ed. New York: Plenum Press.

Blue, E, N., S. C. Mason, and D. H. Sander. 1990. Influence of planting date, seeding rate, and phosphorous rate on wheat yield. Agron. J. 82:762-768.

Dewey, S. A. 1996. Jointed goatgrass-An overview of the problem. Pages 1-2 *in* Proceedings of the Pacific Northwest Jointed Goatgrass Conference. Pocatello, ID: Western Society of Weed Science.

Donald, W. W. 1984. Vernalization requirements for flowering of jointed goatgrass (*Aegilops cylindrica*). Weed Sci. 32:631-637.

Donald, W. W. 1991. Seed survival, germination ability, and emergence of jointed goatgrass (*Aegilops cylindrica*). Weed Sci. 39:210-216.

Donald, W. W. 1994. A method of validating the tetrazolium assay for testing viability of dormant jointed goatgrass (*Aegilops cylindrica*) seed. Weed Sci. 42:502-508.

Donald, W. W. and A. G. Ogg, Jr. 1991. Biology and control of jointed goatgrass (*Aegilops cylindrica*), a review. Weed Technol. 5:3-17.

Donald, W. W. and R. L. Zimdahl. 1987. Persistence, germinability, and distribution of jointed goatgrass (*Aegilops cylindrica*) seed in soil. Weed Sci. 35:149-154.

Fleming, G. F., F. L. Young, and A. G. Ogg, Jr. 1988. Competitive relationships among winter wheat (*Triticum aestivum*), jointed goatgrass (*Aegilops cylindrica*), and downy brome (*Bromus tectorum*). Weed Sci. 36:479-486.

Goemmer, C. 1996. Washington state crop improvement association policies on jointed goatgrass. [Online.] Available: http://ianrwww.unl.edu/ianr/jgg/conf/Goemmer. htm.

Herron, D. 1996. Removing jointed goatgrass from commercial grain and seed. Pages 19-22 *in* Proceedings of the Pacific Northwest Jointed Goatgrass Conference. Pocatello, ID: Western Society of Weed Science.

Karow, R., C. M. Smith, and S. Macnab. 1996. Jointed goatgrass on the move in Oregon. [Online.] Available: http://www.css.orst.edu/Crops/Weeds/jgg.htm.

Larson, R. A. 1997. Seed certification-Policies concerning jointed goatgrass. Proceedings of the 1997 Billings Regional Jointed Goatgrass Conference. [Online.] Available: http://ianrwww.unl.edu/ianr/jgg/billings/larson.htm.

Lyon, D. J. 1993. Jointed goatgrass research in Nebraska. Pages 17-21 *in* P. Westra and R.L. Anderson, eds. Jointed Goatgrass: A Threat to U.S. Winter Wheat. Ft. Collins, CO: Colorado State University.

Lyon, D. J. 1997. Jointed goatgrass biology. Proceedings of the 1997 Billings Regional Jointed Goatgrass Conference. [Online.] Available:http://ianrwww.unl.edu/ianr/ jgg/billings/lyonbiol.htm.

Miller, S. D. and T. Whiston. 1995. Jointed goatgrass. The jointed goatgrass project at the University of Wyoming. [Online.] Available:http://www.uwyo.edu/AG/ PSISCI/Goatgras/goatgrass.htm.

Morrow, L. A., F. L. Young, and D. G. Flom. 1982. Seed germination and seedling emergence of jointed goatgrass (*Aegilops cylindrica*). Weed Sci. 30:395-398.

Ogg Jr., A. G. 1993. Jointed goatgrass survey-1993, Magnitude and scope of the problem. Pages 6-12 *in* P. Westra and R. L. Anderson, eds. Jointed Goatgrass: A Threat to U.S. Winter Wheat. Ft. Collins, CO: Colorado State University.

Trebon, M. 1996. Battling against jointed goatgrass. Capital Press. [Online.] Available: http://ianrwww.unl.edu/ianr/jgg/cp030196.htm.

Walker-Simmons, M. K., and P. J. Goldmark. 1996. Characterization of genes expressed when dormant seeds of cereals and wild grasses are hydrated and remain growth-arrested. Pages 283-291 *in* Lang, G. A., ed. Plant Dormancy: Physiology, Biochemistry, and Molecular Biology. Wallingford, Oxon, UK: Cab International.

Westra, P. and W. Stump. 1995. Using spring crop rotations to control jointed goatgrass. Pages 25-26 *in* Proceedings of the Central Great Plains Jointed Goatgrass Conference. Colby, KS, Ogallala, NE, and Sterling, CO: Western Society of Weed Science.

Willis, B. D., S. A. Dewey, and J. O. Evans. 1989. Elevated canopy and soil temperatures resulting from burning stubble and subsequent jointed goatgrass (*Aegilops cylindrica*) seed germination response. Proc. West. Soc. of Weed Sci. 42:149-150.

Winter, S. R. and J. T. Musick. 1993. Wheat planting date effects on soil water extraction and grain yield. Agron. J. 85:912-916.

Young, F. L., A. G. Ogg Jr., and P. A. Dotray. 1990. Effect of postharvest field burning on jointed goatgrass (*Aegilops cylindrica*) germination. Weed Technol. 4:123-127.

Zemetra, R. S., J. Hansen, M. Lauver, and J. Smith. 1996. The genetics of jointed goatgrass and goatgrass X wheat hybrids. Pages 9-13 *in* Proceedings of the Pacific Northwest Jointed Goatgrass Conference. Pocatello, ID: Western Society of Weed Science.

APPENDICES

Appendix 1

Tables of data collected for all treatments

Table 5. Number of jointed goatgrass spikelets per sample at a depth of 0-5 cm for soil samples taken on November 5, 1997 and elutriated on January 8, 1998.

Treatment			Rep1	Rep2	Rep3	Mean
			Spikelets per sample			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	0	0	0	0
Conservation	September	S-W-W	1	0	0	0.33
Conventional	October	S-W-W	3	0	1	1.33
Conservation	October	S-W-W	0	2	0	0.67
			September wheat			
Conventional	September	W-W-W	10	0	3	4.3
Conservation	September	W-W-W	1	0	0	0.33
Conventional	September	W-S-W	0	0	4	1.33
Conservation	September	W-S-W	1	0	1	0.67
			October wheat			
Conventional	October	W-W-W	33	2	8	14.3
Conservation	October	W-W-W	13	0	11	8
Conventional	October	W-S-W	2	3	5	3.33
Conservation	October	W-S-W	39	1	1	13.7

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

Table 6. Number of jointed goatgrass spikelets per sample at a depth of 5-10 cm for soil samples taken on November 5, 1997 and elutriated on January 8, 1998.

Treatment			Rep1	Rep2	Rep3	Mean
			Spikelets per sample			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	0	0	0	0
Conservation	September	S-W-W	0	0	0	0
Conventional	October	S-W-W	0	1	0	0.33
Conservation	October	S-W-W	0	1	0	0.33
			September wheat			
Conventional	September	W-W-W	3	0	0	1
Conservation	September	W-W-W	0	0	1	0.33
Conventional	September	W-S-W	0	0	5	1.67
Conservation	September	W-S-W	2	0	0	0.67
			October wheat			
Conventional	October	W-W-W	11	0	1	4
Conservation	October	W-W-W	1	0	2	1
Conventional	October	W-S-W	0	4	2	2
Conservation	October	W-S-W	0	0	0	0

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

Table 7. Number of jointed goatgrass spikelets per sample at a depth of 10-15 cm for soil samples taken on November 5, 1997 and elutriated on January 8, 1998.

Treatment			Rep1	Rep2	Rep3	Mean
			Spikelets per sample			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	0	0	0	0
Conservation	September	S-W-W	0	0	0	0
Conventional	October	S-W-W	0	0	0	0
Conservation	October	S-W-W	0	0	0	0
			September wheat			
Conventional	September	W-W-W	1	0	0	0.33
Conservation	September	W-W-W	0	0	0	0
Conventional	September	W-S-W	0	0	1	0.33
Conservation	September	W-S-W	6	0	0	2
			October wheat			
Conventional	October	W-W-W	4	0	0	1.33
Conservation	October	W-W-W	0	0	0	0
Conventional	October	W-S-W	0	0	0	0
Conservation	October	W-S-W	0	0	1	0.33

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b] There is an implied fallow season between each crop.

Table 8. Number of jointed goatgrass seedlings in safflower (April 17), and winter wheat (May 8) crops. 1997.

			Rep1	Rep2	Rep3	Mean
Treatment			Plants m^{-2}			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	8	8	3	6.3
Conservation	September	S-W-W	12	0	3	5
Conventional	October	S-W-W	29	12	2	14.3
Conservation	October	S-W-W	29	1	10	13
			September wheat			
Conventional	September	W-W-W	18	4	29	17
Conservation	September	W-W-W	26	2	10	12.7
Conventional	September	W-S-W	14	2	2	6
Conservation	September	W-S-W	8	3	15	8.7
			October wheat			
Conventional	October	W-W-W	14	10	5	9.7
Conservation	October	W-W-W	12	16	13	13.7
Conventional	October	W-S-W	4	6	14	8.7
Conservation	October	W-S-W	14	18	14	15.3

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

Table 9. Mid-season jointed goatgrass plant counts in safflower. 1997. Jointed goatgrass populations determined June 30.

Treatment			Rep1	Rep2	Rep3	Mean
Tillage	Planting date	Rotation	plants/m^2			
Conventional	September	S-W-W[a]	0.465	0.272	0.237	0.325
Conservation	September	S-W-W	0.254	0.387	0.314	0.318
Conventional	October	S-W-W	0.416	0.263	0.366	0.348
Conservation	October	S-W-W	0.228	0.448	0.409	0.362

[a] There is an implied fallow season between each crop.

Table 10. Jointed goatgrass plant counts taken on april 21, 1998 in fallow following wheat and safflower.

			Rep1	Rep2	Rep3	Mean
Treatment			Plants m^{-2}			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	2	11	0	4.3
Conservation	September	S-W-W	2	7	0	3.0
Conventional	October	S-W-W	2	0	2	1.3
Conservation	October	S-W-W	1	1	16	6.0
			September wheat			
Conventional	September	W-W-W	39	1	0	13.3
Conservation	September	W-W-W	1	10	3	4.67
Conventional	September	W-S-W	1	0	0	0.33
Conservation	September	W-S-W	3	38	1	14
			October wheat			
Conventional	October	W-W-W	15	6	10	10.3
Conservation	October	W-W-W	14	46	4	21.3
Conventional	October	W-S-W	24	20	15	19.7
Conservation	October	W-S-W	5	15	5	8.33

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.
[b]There is an implied fallow season between each crop.

Table 11. Plant counts taken on april 21, 1998 in wheat and unplanted safflower plots during the first year of the replicate experiment.

Treatment			Rep1	Rep2	Rep3	Mean
			Plants m^{-2}			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	6	13	8	9.0
Conservation	September	S-W-W	14	2	11	9.0
Conventional	October	S-W-W	22	10	8	13.3
Conservation	October	S-W-W	9	30	2	13.7
			September wheat			
Conventional	September	W-W-W	8	3	6	5.7
Conservation	September	W-W-W	4	5	12	7.0
Conventional	September	W-S-W	5	6	14	8.3
Conservation	September	W-S-W	6	8	4	6.0
			October wheat			
Conventional	October	W-W-W	4	9	2	5.0
Conservation	October	W-W-W	2	3	5	3.3
Conventional	October	W-S-W	3	10	5	6.0
Conservation	October	W-S-W	1	1	8	3.3

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

Table 12. Mid-season jointed goatgrass plant counts in safflower, 1998. Jointed goatgrass populations determined May 27.

Treatment			Rep1	Rep2	Rep3	Mean
Tillage	Planting date	Rotation	plants/m^2			
Conventional	September	S-W-W[a]	0.457	0.479	0.246	0.394
Conservation	September	S-W-W	0.377	0.554	0.242	0.271
Conventional	October	S-W-W	0.178	0.554	0.242	0.325
Conservation	October	S-W-W	0.463	0.441	0.183	0.362

[a]There is an implied fallow season between each crop.

Table 13. 1997 yield taken for wheat and safflower in experiment one. Wheat was harvested on August 25, safflower was harvested on September 26.

			Rep1	Rep2	Rep3	Mean
Treatment			kg[c]			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	4.8	5.4	4.6	4.9
Conservation	September	S-W-W	5.7	7.2	5.2	6.0
Conventional	October	S-W-W	7.1	6.8	6.4	6.8
Conservation	October	S-W-W	6.0	6.0	6.4	6.1
			September wheat			
Conventional	September	W-W-W	22.6	21.8	17.6	20.7
Conservation	September	W-W-W	21	22.9	20	21.3
Conventional	September	W-S-W	20.6	20.7	17.7	19.7
Conservation	September	W-S-W	22.3	24.5	19.4	22.1
			October wheat			
Conventional	October	W-W-W	16.1	16.1	18	16.7
Conservation	October	W-W-W	15.5	16.7	16.7	16.3
Conventional	October	W-S-W	16	14.9	19.3	16.7
Conservation	October	W-S-W	14.4	17.3	16.3	16.0

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

[c]Harvested are for experiment one was 61 m^2.

Table 14. 1998 yield data taken for wheat and safflower. Wheat was harvested on September 1, safflower was harvested on September 26.

			Rep1	Rep2	Rep3	Mean
Treatment			kg[c]			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	1.3	1.7	2.1	1.7
Conservation	September	S-W-W	0.9	1.0	1.4	1.1
Conventional	October	S-W-W	3.0	1.7	1.4	2.0
Conservation	October	S-W-W	1.3	0.9	3.0	1.7
			September wheat			
Conventional	September	W-W-W	17.3	29.6	17.4	21.4
Conservation	September	W-W-W	30.7	18.7	27.7	25.7
Conventional	September	W-S-W	24.2	28.2	20.5	24.3
Conservation	September	W-S-W	29.1	21.1	21.8	24.0
			October wheat			
Conventional	October	W-W-W	20.7	17.6	16.5	18.2
Conservation	October	W-W-W	7.1	15.5	18.0	13.5
Conventional	October	W-S-W	23.0	17.7	18.1	19.6
Conservation	October	W-S-W	8.6	13.7	19.3	13.9

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

[c]Harvested area in experiment two was 48.8 m^2, except for the third repetition of September planting date for all rotations (S-W-W, W-W-W, and W-S-W) which had a harvested area of 42.7 m^2.

Table 15. 1997 crop contamination data collected for wheat and safflower. Wheat was harvested on August 15, safflower was harvested on September 26.

Treatment			Rep1	Rep2	Rep3	Mean
			g/kg			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	0.00	0.00	0.42	0.14
Conservation	September	S-W-W	0.27	3.03	0.00	1.10
Conventional	October	S-W-W	0.00	0.00	0.91	0.30
Conservation	October	S-W-W	0.98	2.01	0.00	1.00
			September wheat			
Conventional	September	W-W-W	0.43	0.00	2.34	0.92
Conservation	September	W-W-W	1.11	0.15	0.09	0.45
Conventional	September	W-S-W	0.26	0.10	0.15	0.17
Conservation	September	W-S-W	0.47	1.17	0.25	0.63
			October wheat			
Conventional	October	W-W-W	1.29	2.71	2.39	2.13
Conservation	October	W-W-W	1.95	3.13	0.97	2.02
Conventional	October	W-S-W	1.89	2.42	1.83	2.05
Conservation	October	W-S-W	1.20	5.10	3.61	3.30

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b] There is an implied fallow season between each crop.

Table 16. 1998 crop contamination data collected for wheat and safflower. Wheat was harvested on August 24. Safflower was harvested on October 20.

Treatment			Rep1	Rep2	Rep3	Mean
			g/kg			
Tillage	Planting date	Rotation[a]	Safflower			
Conventional	September	S-W-W[b]	--	--	--	--
Conservation	September	S-W-W	--	--	--	--
Conventional	October	S-W-W	--	--	--	--
Conservation	October	S-W-W	--	--	--	--
			September wheat			
Conventional	September	W-W-W	31.4	23.3	36.8	30.5
Conservation	September	W-W-W	23.3	20.5	25.3	23.0
Conventional	September	W-S-W	18.7	23.6	27.8	23.4
Conservation	September	W-S-W	19.1	21.3	23.2	21.2
			October wheat			
Conventional	October	W-W-W	35.1	51.1	26.9	37.7
Conservation	October	W-W-W	57.1	21.3	25.7	34.7
Conventional	October	W-S-W	42.1	52.6	38.1	44.3
Conservation	October	W-S-W	29.2	43.8	38.9	37.3

[a] Crop rotation abbreviations are: W-W-W for three consecutive wheat crops, W-S-W for wheat followed by safflower followed by wheat, and S-W-W for safflower followed by two wheat crops.

[b]There is an implied fallow season between each crop.

Appendix 2

ANOVA tables for all treatments

Table 17. Analysis of variance for wheat yield, and before and after planting counts of jointed goatgrass in safflower in 1997 and 1998.

Source of Variance	df	Wheat Yield 1997 MS	F	Wheat Yield 1998 MS	F	Plants m^{-2} Safflower 1997 MS	F	Plants m^{-2} Safflower 1998 MS	F
Rep	11	10.5	0.4	80.7	0.2	48.9	1.0	32.3	1.0
Treatment	1	728.2**	28.0	4195**	12	531.4**	10.8	714.4**	22.5
Error	11	26.0	--	349.7	--	49.3	--	31.8	--

** denotes significance at the 0.01 probability level.

Table 18. Analysis of variance of crop contamination in 1997 and 1998.

Source of Variance	df	1997 MS	1997 F	1998 MS	1998 F
Rep	11	954.4	1.7	114589	1.9
Treatment	2	8835**	15.9	1302936**	21.3
Error	22	555.5	--	61060	--

** denotes significance at the 0.01 probability level.

Table 19. Analysis of variance of jointed goatgrass plant counts in wheat and unplanted plots in 1997 and 1998.

Source of Variance	df	1997-1 [a] MS	F	1998-1 MS	F	1998-2 MS	F
Rep	11	41.2	0.7	154.5	1.45	9.9	0.7
Treatment	2	338**	6.1	577.1**	5.4	171**	12.5
Error	22	55.7	--	106.8	--	13.6	--

** denotes significance at the 0.01 probability level. [a]1 is Experiment One and 2 is Experiment 2.

Table 20. Analysis of variance of jointed goatgrass plant counts using data collected from experiments one and two in 1997 and 1998.

Source of Variance	df	MS	F
Rep	11	21.2	0.6
Year	1	151.6	4.1
R x Y(Error a)	11	36.7	--
Treatment	3	489.4**	13.6
Y x T	3	96.6	2.7
R x T	33	42.2	1.2
R x T x Y (Error b)	33	36.1	--

** denotes significance at the 0.01 probability level.

Table 21. Analysis of variance for comparisons of soil seedbank concentrations at 0-5, 5-10, and 10-15cm depths in 1997.

Source of Variance	df	MS	F
Rep	11	41.9	1.8
Treatment	2	139.8**	5.6
R x T (Error a)	22	23.5	--
Depth	1	139.8**	8.1
R x D	11	18.4	1.1
T x D	2	88.1**	5.1
R x T x D (Error b)	22	17.3	--

** denotes significance at the 0.01 probability level.

Table 22. Analysis of variance of wheat yield over 2-yr (experiments one and two).

Source of Variance	Df	MS	F
Year	1	3676.54**	78.7
Rep	11	60.30	1.3
Y x R (Error a)	11	46.69	--
Treatment	1	3814.81**	22.1
Y x T	1	889.98*	5.1
R x T	11	206.77	1.2
Y x R x T (Error b)	11	172.96	--

*,** denote significance at the 0.05 and 0.01 probability levels, respectively.