FINAL REPORT

National Jointed Goatgrass Research Program (1994-2009)

I. Executive Summary:

The National Jointed Goatgrass Research Program was initiated in 1994 by using a special USDA grant to fund regional research and extension activities directed toward limiting the damage caused by jointed goatgrass to winter wheat production in the western United States. In 1993, it was estimated that nearly 5 million acres of farmland were infested with jointed goatgrass and that the weed was costing wheat producers ~$45 million/yr as a result of decreased wheat yield caused by direct competition with the weed and reduced quality and prices for the harvested wheat due to weed seed contamination. During the 15-year life of the Program, a total of $4.1 million of National Jointed Goatgrass Research Program funds were used to support jointed goatgrass research and technology transfer projects in 10 western states (WA, OR, ID, UT, WY, MT, CO, NE, KS, and OK) where jointed goatgrass is a problem. Long-term funding for the Jointed Goatgrass Program was requested by the wheat industry, which also contributed to the Program through the active participation of wheat producers and wheat industry personnel on the National Steering Committee that directed the Program. Initially, the Program focused on developing individual cultural practices that producers could adopt to help reduce the negative impacts of jointed goatgrass. During the middle and later years of the Program, the focus was on merging these into long-term management systems that integrated numerous cultural weed control practices and herbicide-resistant wheat technology. Technology transfer activities were an integral part of this Program from the beginning, when seven producer-orientated workshops were held in the main winter wheat producing areas where jointed goatgrass was a problem. Five national bulletins were published that summarized the National Jointed Goatgrass Research Program and the state of the knowledge on jointed goatgrass biology, genetics, control tactics and herbicide resistant management. At the end of the program, four regional bulletins were published that provided wheat producers with region-specific strategies for the integrated management of jointed goatgrass in winter wheat production systems. These can be obtained through an open access website, www.jointedgoatgrass.org, which was established in 1996 to provide the latest research findings to the agricultural community. Because of the success of this national program, there has been widespread adoption of the research findings, allowing producers to implement an integrated, science-based approach to managing jointed goatgrass.

II. Summary Impact Statement:

The National Jointed Goatgrass Research Program supported 15 to 20 projects per year for a total USDA Special Grant expenditure of just over $4 million, so the average support for each grant was about $17,000/year. These federal funds were leveraged and facilitated coordination of important additional resources at the cooperating institutions so the total investment for research and extension was much higher and included support by the home institution of the investigator, investigator salaries, wheat industry support, etc. The community organized around the Special Grant was able to solicit and support the diverse research and extension expertise needed for the task while minimizing overlapping effort and expense. Viable strategies for limiting the spread of jointed goatgrass have been developed and farmers in 10 states are integrating these into their production strategies. The national jointed goatgrass website www.jointedgoatgrass.org has provided world-wide access to all of the information generated by this Program. During the life of the Program, scientists published 78 refereed manuscripts and 20 M.S. and PH. D. theses covering their research and technology transfer activities. Also, five national and four regional extension bulletins were published. The Program supported the education and training of 21 graduate students. This national program has provided wheat producers with the necessary tools to control a previously uncontrolled weed, and thus the Program has improved farm profitability and sustainability.

The benefits to agriculture and science from this Program will continue for many years. This program has set a new standard for weed science research in being able to integrate multiple disciplines and organizations to provide integrated management systems that were adopted by producers to control a major weed problem.

III. Specific Research Accomplishments and Impacts:

The Program focused on the biology of jointed goatgrass in order to understand how the weed was able to do so well under the winter wheat production practices that were being used and it tested alternatives to these practices in order to differentially impact the weed. Major areas of this effort included understanding how jointed goatgrass seed was generated, conditions that it needed for germination and the potential of interfering with the growth of jointed goatgrass through changes in winter wheat production methods, including altering soil cultivation, crop rotation strategies, fallowing practices, incorporating herbicide resistant wheat cultivars into winter wheat rotations and integrating jointed goatgrass management with the management of other weeds that are problems in winter wheat. To estimate the long-term impact of some of these changes, the Program also supported research into the genetic structure of jointed goatgrass populations, the potential for gene exchange between jointed goatgrass and wheat, and the economic consequences of changes in production practices. As appropriate, science-based suggestions for changes in winter wheat production were communicated to producers and the results of producer implementation of production alternatives were followed. Specific accomplishments are listed below in approximate chronological order.

Accomplishment: Jgg seed biology. Seed from spikelets located at the bottom or middle positions on the spike of jointed goatgrass germinated quicker and at higher frequencies than seed from spikelets from the upper one-third of the spike. Spikelets at the base of the spike produced more seed than spikelets near the tip of the spike. Increasing the length of the vernalization period increased the shoot length, root length and total dry weight of jointed goatgrass. Dormancy in jointed goatgrass seed was more a function of the environment in which the seed was grown and the temperature after harvest than of genetic variation in jointed goatgrass. Cool temperatures during seed development and warm temperatures during after-ripening shorten the dormancy period in jointed goatgrass seed. Seed mass of jointed goatgrass was correlated positively with speed of germination, with heavier seed germinating more rapidly than lighter seed. High temperature, low moisture conditions and high nitrogen concentrations greatly reduced the number of spikes and spikelets produced per jointed goatgrass plant.

Impact: Basic weed biology data helps explain how jointed goatgrass grows and reproduces, and provided information useful in making integrated weed management systems more effective.

Accomplishment: Microbial decay of seed. The soil microbial community surrounding jointed goatgrass spikelets in the soil changed over time. Fatty acid analysis of microorganisms showed that spikelets decomposed most rapidly in soil conditions in which naturally occurring bacteria dominated early, followed by a strong increase in fungi. Some strains of microorganisms also inhibited seed germination and growth of jointed goatgrass. Decaying jointed goatgrass seed releases distinct fatty acids and the presence and the quantity of these compounds may provide an indicator of the decay process.

Impact: Identification of microorganisms on decaying jointed goatgrass spikelets may lead to methods or materials that will increase the decay rate of seeds buried in the soil and thereby reduce the negative impact of jointed goatgrass on wheat production.

Accomplishment: Soil differences impact seed germination. Compared to a soil from Colorado, a soil from Oklahoma was more acidic, had lower concentrations of phosphorus and zinc and higher concentrations of potassium and iron. Microbial numbers in the two soils were similar, although the microbial community compositions differed. Under controlled conditions, more jointed goatgrass seedlings emerged from the Oklahoma soil than the Colorado soil. More seedlings emerged from the Oklahoma soil after it was sterilized than before it was sterilized, indicating that soil organisms were inhibiting jointed goatgrass spikelets/seed. These results indicate that germination and emergence of jointed goatgrass can differ as a function of the geographic location of the soil and that soil microbial communities were degrading jointed goatgrass spikelets and or seed more rapidly in the Oklahoma soil compared to the soil from Colorado.

Impact: Results from this study helps to explain why jointed goatgrass spikelets/seed are less persistent in Oklahoma soil than in soil from Colorado. This information may explain why certain cultural practices are more effective in Oklahoma than in Colorado. Also, data from this study could provide information needed to advance biocontrol strategies for managing jointed goatgrass using soil microorganisms.

Accomplishment: Moldboard plowing. Moldboard plowing where the furrow slice was completely inverted was highly effective in reducing the emergence of jointed goatgrass in the next winter wheat crop. Burning the stubble before plowing did not improve jointed goatgrass control. Compared to spring disking, deep, moldboard plowing in the spring before fallow in NE reduced jointed goatgrass 100% and increased wheat yields 58% in the first year after plowing. In OK, annual moldboard plowing for 2 yr in a continuous winter wheat system reduced the jointed goatgrass populations to low levels and after 4 years reduced jointed goatgrass populations in winter wheat to near zero. In contrast, the use of stubble mulch systems for 4 years dramatically increased jointed goatgrass populations.

Impact: Moldboard plowing provides wheat producers with an effective tool for controlling jointed goatgrass. However, because of potential erosion problems after plowing, this practice should be limited to small areas and to fields not susceptible to erosion. In areas where winter wheat is grown continuously, producers should not use stubble mulch practices until jointed goatgrass populations have been controlled.

Accomplishment: Expanding crop rotations. Increasing crop diversity to extend the interval between winter wheat crops greatly reduced the severity of jointed goatgrass infestations. Longer crop rotations depleted the jointed goatgrass soil seedbank. Extending a wheat-fallow rotation by adding a spring or summer crop reduced the density of jointed goatgrass by as much as 90%. Extending the rotation to four years by adding two alternate spring or summer crops reduced the jointed goatgrass population to near zero. Corn, sorghum and sunflower were suitable rotational crops in areas with mild winters and abundant summer rain. When summer rainfall was low, sunflowers, which can extract soil moisture to a depth of 10 feet, reduced yields of the following wheat crop by 12% in KS. In UT, adding safflower to the traditional winter wheat-fallow rotation to have a winter wheat-safflower-fallow rotation increased wheat yields 19 to 42% and reduced jointed goatgrass populations in wheat by 14 to 40%. Spring wheat, spring barley, peas and lentils were suitable rotational crops in the Pacific Northwest. However, if these spring crops were planted early using no-till practices, jointed goatgrass could emerge, vernalize, and produce a few viable seeds, thus reducing the effectiveness of crop rotation in this system. In the drier winter wheat-fallow areas of the Pacific Northwest, it is difficult to extend the rotation because of the lack of suitable spring crops that are profitable. Jointed goatgrass populations increased dramatically in both wheat-fallow and wheat-sorghum-fallow rotations grown under no-till systems in OK, although weed populations were lowest in the wheat-sorghum-fallow system.

Impact: Extending the time between winter wheat crops was the single most effective cultural practice for reducing jointed goatgrass. In higher rainfall areas, it is possible to extend the rotation so wheat is grown only once every four years. For example, in UT, about 20% of the producers using a traditional wheat-fallow rotation have added safflower to their rotations to help manage jointed goatgrass. This has improved farm profitability compared to the traditional winter wheat-fallow system.

Accomplishments: Individual cultural practices.

Increasing winter wheat seeding rates by up to 100% of the recommended seeding rates suppressed jointed goatgrass growth and spikelet production, increased grain yield and reduced dockage resulting from jointed goatgrass contamination. However, high seeding rates for wheat cannot be used in the low rainfall areas of the Pacific Northwest and the Intermountain regions.

Narrow wheat row spacing sometimes reduced jointed goatgrass growth and spikelet production and increased the grain yield of winter wheat. Results varied from year to year and site to site, often depending on the timing and amount of precipitation received.

Adding nitrogen fertilizer in a deep band near the wheat seed row at planting time reduced jointed goatgrass tillers and spikelet production by as much as 50% compared to broadcasting the nitrogen at planting time or during the growing season. Dockage due to jointed goatgrass contamination was twice as high when nitrogen was broadcast on the soil surface compared to deep banding or spoke injection. Also, wheat yielded better when nitrogen was deep banded or spoke injected compared to surface broadcast applications of nitrogen. Placing nitrogen fertilizer below and near the seed row allows wheat earlier and preferential access to the nitrogen compared to jointed goatgrass, which grows as scattered plants mostly between the rows of wheat.

Seeding large wheat seed compared to small wheat seed increases wheat seedling vigor and enhanced the competitiveness of the crop relative to jointed goatgrass.

Delayed seeding of winter wheat in the fall seldom improved the winter wheat's ability to compete with jointed goatgrass and frequently reduced grain yields compared to seeding wheat at the date that would be chosen in the absence of the weed.

In dry environments, wheat cultivars differ significantly in their ability to compete with jointed goatgrass. Generally, tall cultivars are more competitive than short cultivars, but there were instances where shorter cultivars were more competitive with jointed goatgrass than tall cultivars. In addition to plant height, other wheat traits associated with higher competitiveness included rapid germination and emergence, rapid early growth, high tiller number and high water uptake (rapid root growth).

Impact: Individual cultural practices sometimes suppressed jointed goatgrass growth and spikelet production and sometimes increased winter wheat yields. Results varied significantly from year to year and from location to location indicating individual cultural practices were not consistently effective for managing jointed goatgrass. However, information on individual cultural practices provided the elements for the development of integrated weed management systems for suppressing jointed goatgrass.

Accomplishment: Detecting competitive cultivars. A portable spectrometer that recorded reflectance at 670 and 780 nanometers was used to rapidly and non-destructively detect differences in the growth patterns of different winter wheat cultivars. Reflectance data were used to calculate a normalized difference vegetative index (NDVI). When NDVI was measured in mid-January in OK, wheat cultivars with higher NDVI readings were more competitive with jointed goatgrass and yielded more. Wheat cultivars that had rapid germination after planting, rapid early growth, high biomass accumulation, and rapid height gain were most competitive with jointed goatgrass.

Impact: NDVI was useful for screening wheat cultivars for competitive ability against jointed goatgrass, and may be useful for identifying plant characteristics that impart competitive ability to wheat plants.

Accomplishment: Timing of fallow tillage. Precipitation patterns appear to have a greater impact on jointed goatgrass germination and emergence in fallow than timing or intensity of tillage. In some years, early post harvest tillage enhanced the germination of jointed goatgrass seed in the soil during the fallow year. In other years, early spring tillage in fallow was most effective in reducing jointed goatgrass seedbanks. Regardless of when it was initiated, fallow tillage did not reduce the number of jointed goatgrass plants growing in the next winter wheat crop.

Impact: Because fallow tillage was not a reliable practice for enhancing the germination of jointed goatgrass seed in fallowed soil, producers can reduce tillage in fallow and thereby conserve moisture and reduce production costs.

Accomplishment: Integrating weed management systems. Anderson (1997) demonstrated that combining several individual cultural control practices into a system was more effective than using a single cultural practice for suppressing jointed goatgrass in winter wheat. Based on this information, four long-term integrated management projects were established in the winter wheat producing areas of the western US. Success of these projects varied. Generally, wheat production systems that included multiple weed cultural control practices reduced the growth and seed production of jointed goatgrass and increased wheat yields.

- In WA and OR in three of four cycles of a winter wheat-fallow rotation, integrated weed management systems (IWMS) that included one-time stubble burn, increased length of crop rotation, planting large wheat seed, increased seeding rate, and planting a competitive wheat variety increased wheat yields an average of 22% and reduced dockage due to jointed goatgrass 85% compared to standard winter wheat production systems.

- In central NE after 9 years of testing crop rotations, winter wheat yields were increased over 300% when one or two corn crops were included in a wheat-fallow rotation largely by suppressing jointed goatgrass by 99%. Preventing weed growth after wheat harvest and beginning fallow tillage in April were important farming practices for reducing jointed goatgrass populations. Wheat variety selection and fallow tillage practice had little impact on jointed goatgrass populations in the wheat crop.

- Extending a two-year wheat-fallow rotation in western KS to include one or two summer crops reduced jointed goatgrass populations more than changing the fallow method (chemical or tillage) or wheat cultivar. Yearly environmental differences (mostly rainfall and temperatures during the first two months after wheat was planted) greatly affected establishment, growth and seed production of jointed goatgrass.

In all areas studied, weather stress events, like drought, hail storms, freeze injury, disease infections or insect infestations, could reduce the competitiveness of the wheat crop and increase the growth and spikelet production of jointed goatgrass. One such event could return jointed goatgrass seed levels in the soil to the original, high levels.

Impact: Progressive wheat producers are adopting IWMS for controlling jointed goatgrass in winter wheat. In some instances, adoption of integrated systems has been slowed because of the need for greater management time and more precise timing of farming practices for IWMS. Also, adoption of integrated systems has been slow because such systems are more susceptible to variations in weather conditions and pest problems than traditional farming practices. In some instances, the adoption of IWMS in a specific region cannot be implemented because of the lack of adequate rainfall or economically viable alternative crops.

Long-term regional projects demonstrated to producers that, by combining several cultural weed control practices into an integrated management system, they can reduce the impact of jointed goatgrass on wheat production and can increase farm profitability. Because these long-term projects were located in all of the major winter wheat producing areas where jointed goatgrass is a problem, these projects are providing site-specific information that producers in the area can easily relate to and thus adapt to their local circumstances.

Accomplishment: Diversity in jointed goatgrass. Jointed goatgrass accessions collected from the major winter wheat producing areas in the western US and grown in a common nursery at Colorado State University differed significantly in morphological traits within a given year. However, there were significant year by accession interactions suggesting that environmental effects were affecting the morphological development of the accessions differently. DNA fingerprinting of the accessions showed very little genetic diversity among the accessions.

Impact: Because there was little genetic diversity among jointed goatgrass accessions, jointed goatgrass plants in the different wheat producing areas in the western US would be expected, under similar environmental conditions, to respond similarly to specific management practices. This would be especially important for biocontrol and herbicide application practices.

Accomplishment: Herbicide safeners. Dimethenamid-p (Outlook™) controls jointed goatgrass, but injures wheat. Although the herbicide safener, fluxofenim, increased the tolerance of wheat to the herbicide, the crop was still injured. Recently, scientists isolated the gene for the enzyme, glutathione S-transferase (GST), which metabolizes herbicides such as dimethenamid-p.

Impact: This information will enable scientists to screen for herbicide tolerant and safener-responsive lines of wheat, and ultimately could lead to more herbicide tolerant wheat and improved control of jointed goatgrass.

Accomplishment: Imi-Wheat Technology. Some wheat cultivars are more resistant than jointed goatgrass to imidazolinone herbicides and these herbicides can be used to suppress jointed goatgrass to acceptable levels. However, control of jointed goatgrass in imidazolinone-resistant wheat using the herbicide imazamox (Imi-Wheat Technology™) differed significantly between years and locations, and varied from 39% to 99%. Control was reduced when drought conditions forced the imazamox application to be delayed from fall to spring. Split applications by using fall and spring application times frequently improved control of jointed goatgrass. Using best management practices with Imi-Wheat Technology reduced jointed goatgrass populations 85 to 95% compared to conventional winter wheat production systems.

Impact: Imi-Wheat Technology has provided wheat producers with a valuable tool for controlling jointed goatgrass. Imi-Wheat can be effective when used alone under optimum conditions, but control of jointed goatgrass is often improved when combined with effective cultural practices. The use of Imi-Wheat Technology has been limited in some wheat producing regions by its high cost and the lack of locally adapted, high-yielding varieties.

When used without other cultural control practices, Imi-Wheat Technology can have limited success under some field conditions, such as drought.

Accomplishment: Gene flow from wheat to jgg. Resistance of Imi-Wheat to imazamox is determined by a few wheat genes, leading to concerns about potential gene flow transferring resistance to jointed goatgrass. Jointed goatgrass was shown to hybridize with winter wheat under field conditions and these hybrids produced a small amount of viable seed. Jointed goatgrass was the maternal parent in 62 to 84% of the hybrids. When hybrids between jointed goatgrass x resistant wheat were backcrossed with jointed goatgrass for several successive generations under field conditions, they produced jointed goatgrass plants that were fully self-fertile and resistant to imidazolinone herbicides. Because of the low level of viable seed from crosses between wheat and jointed goatgrass and the low self-fertility of the hybrid plants, it is unlikely but not impossible that jointed goatgrass populations resistant to imidazolinone herbicides will arise by hybridization and backcrossing in the field.

Impact: Because jointed goatgrass can hybridize with winter wheat, genes from herbicide resistant wheat can be transferred to jointed goatgrass after several successive backcrosses with jointed goatgrass. Although the probability of developing herbicide-resistant jointed goatgrass by this process is low, should genes be transferred to jointed goatgrass, gene transfer would make imadazolinone-resistant wheat technology ineffective for controlling jointed goatgrass. Like most gene transfer possibilities, the scale of opportunity and the ability to survive herbicide treatment before the fertility of the hybrids is restored by backcrossing are important factors to consider. The demonstration that such transfer is possible should motivate producers using current and future herbicide-resistant wheat technologies to follow good resistance management practices.

Accomplishment: Gene placement in wheat. Wheat and jointed goatgrass are polyploidy hybrids; wheat has three original parents (ABD) and jointed goatgrass has two (CD). Because both plants have the D genome in common, it was speculated that transferring herbicide resistance would be easier if the herbicide resistance genes were on the D genome. However, placing herbicide-resistant genes on the A or the B wheat genomes rather than the D genome did not eliminate the movement of these genes via pollen to jointed goatgrass. Furthermore, homozygosity for the resistance gene could be established by backcrossing to jointed goatgrass.

Impact: Changing the genome location of herbicide-resistant genes from the D genome of wheat to either the A or B genome will reduce but not eliminate the risk of genetic transfer of herbicide-resistant genes from wheat to jointed goatgrass. This finding indicates that genome placement may help but cannot ensure the durability of herbicide-resistant wheat as a strategy for controlling jointed goatgrass.

<u>Accomplishment: Herbicide-resistant jgg.</u> Occasionally, a few jointed goatgrass plants survive field applications of imazamox and produce viable seed. Some plants from these seeds were grown in the greenhouse and survived several applications of imazamox. However, dose-response tests showed that these plants were not homozygous for imidazolinone-resistance. The discovery of jointed goatgrass plants that tolerated multiple applications of imazamox, but failed the dose-response test, suggests the parental plants may have had some form of metabolic resistance to imidazolinone herbicides.

<u>Impact:</u> If subsequent research confirms that metabolic resistance to imazamox can occur in jointed goatgrass, this will increase the risk that imidazolinone-resistant wheat technology will not be an effective long-term strategy for controlling jointed goatgrass.

<u>Accomplishment: No-till spring cereals and herbicide-resistant wheat.</u> In WA, a no-till spring cereals-chemical fallow rotation was significantly more effective than a no-till herbicide-resistant winter wheat-chemical fallow rotation in reducing jointed goatgrass populations. One-time deep plowing increased the effectiveness of no-till spring cereals in suppressing jointed goatgrass populations. Shallow disking before planting spring cereals was more effective than no-till planting for reducing jointed goatgrass populations and spikelet production.

<u>Impact:</u> Results from this study provided wheat producers with easily-adopted practices that improved the effectiveness of spring cereals in suppressing jointed goatgrass in winter wheat production systems.

<u>Accomplishment: Integrating imi-resistant wheat in WA.</u> In WA, imidazolinone-resistant winter wheat planted for two consecutive cycles of either a 2-year or 3-year crop rotation reduced jointed goatgrass populations to very low levels. There was no significant benefit in reducing jointed goatgrass populations from using Imi-wheat Technology for three consecutive cycles compared to using the Technology for only two consecutive cycles. Using Imi-wheat Technology in every other cycle was less effective than using the Technology for two consecutive cycles. Not using Imi-wheat Technology for one cycle after two consecutive cycles allowed jointed goatgrass populations to increase dramatically.

<u>Impact:</u> Wheat producers need not use Imi-wheat Technology every cycle in a crop rotation to manage jointed goatgrass, thus production costs are reduced and the risk of developing herbicide-resistant jointed goatgrass is also reduced.

<u>Accomplishment: Integrating imi-resistant wheat in CO.</u> In CO, Imi-Wheat Technology reduced joint goatgrass reproductive tillers by 92% the first year. Using this Technology for six consecutive cycles of wheat-fallow rotation reduced jointed goatgrass populations by 99%. However, in the seventh year, conditions favorable to the germination and growth of jointed goatgrass dramatically increased jointed goatgrass reproductive tillers prior to spraying with imazamox. Over the seven-year study, the Imi-Wheat system compared with the conventional wheat production system increased winter wheat yield by 8%.

Impact: Imi-Wheat Technology has provided winter wheat producers with a highly effective tool for managing jointed goatgrass, but given ideal conditions for jointed goatgrass germination, jointed goatgrass populations can rebound rapidly when the Technology is not used. Wheat producers need to remain vigilant for jointed goatgrass in their wheat fields even after using Imi-Wheat Technology for several consecutive years.

Accomplishment: Integrating imi-resistant wheat in WY and western NE. In southeastern WY, the use of Imi-Wheat Technology for three cycles of a wheat-fallow rotation reduced jointed goatgrass reproductive tillers by 94%. The effect of using Imi-Wheat Technology for two cycles on jointed goatgrass carried over to the next wheat crop in a wheat-fallow system and reduced the number of reproductive tillers compared to using the Technology only once. Consecutive use of Imi-Wheat Technology increased the appearance of herbicide-resistant wheat x jointed goatgrass hybrids and increased the possibility of developing herbicide-resistant jointed goatgrass.

Impact: The use of Imi-Wheat Technology in each cycle of a wheat-fallow system will control jointed goatgrass, but is thought to favor the development of herbicide-resistant jointed goatgrass. Based on these findings, producers should not use Imi-Wheat Technology more than twice in a six-year period.

Accomplishment: Integrating imi-resistant wheat in western KS. Combining Best management practices (BMPs) with Imi-Wheat Technology dramatically reduced jointed goatgrass populations compared to using conventional wheat grown with BMPs. Jointed goatgrass densities in conventional wheat systems varied widely from year to year depending on fall environmental conditions, whereas, weed populations remained low in the Imi-Wheat production system. There was no advantage in terms of jointed goatgrass populations in using Imi-Wheat Technology for three consecutive years compared to using the Technology for two consecutive years.

Impact. Imi-Wheat Technology has provided wheat producers with an effective tool to manage jointed goatgrass even when environmental conditions are not favorable for growing a competitive wheat crop. Producers can improve weed control effectiveness and farm profitability by using BMPs with Imi-Wheat Technology.

Accomplishment: Integrating imi-resistant wheat in OK. Jointed goatgrass populations increased dramatically and remained high when wheat was grown for five consecutive years in a stubble mulch system compared to a system where fields were either moldboard plowed each year, or where Imi-Wheat was planted and treated with imazamox each year. In terms of jointed goatgrass populations, it was better to use Imi-Wheat Technology for two consecutive years than to use the Technology every other year.

Impact: Imi-Wheat Technology has given wheat producers in the southern High Plains a method to grow continuous winter wheat under the conservation practice of stubble-mulch farming. This research showed that producers could skip using Imi-Wheat Technology for one or more years if they used the Technology for two consecutive years, thus reducing production costs and decreasing the risk of selecting for herbicide-resistant jointed goatgrass.

Accomplishment: Impact of weed density on crop yield. Response of winter wheat to competition from various populations of jointed goatgrass varied significantly among sites in eight western US states. Site-specific weather, crop density and relative time of crop and weed emergence accounted for much of the variation.

Impact: Site-specific variation in the response of winter wheat to a given population of jointed goatgrass makes it more difficult to use bio-economic models to predict accurately how much a given population of jointed goatgrass would reduce wheat yields.

Accomplishment: JGG bio-economical model. A bio-economical model (JGGBEM) was developed using 31 data sets and site-specific weather data from eight western US states. The model was composed of a jointed goatgrass demographic sub-model, a crop sub-model and an economic sub-model. For example, the model predicted that a cropping system that included a spring crop of sunflowers in the traditional winter wheat-fallow system would maximize annualized returns and decrease jointed goatgrass seed banks significantly. Field research in UT verified this prediction.

Impact: The complexity of the jointed goatgrass bio-economical model and the inability of the current model to handle different crop rotations have limited its usefulness to wheat producers. However, the model has been useful to weed scientists for studying weed-crop competition and jointed goatgrass biology.

IV. Specific Technology Transfer Accomplishments and Impacts:

Accomplishment: Regional conferences and tours. Meetings and research tours focused on jointed goatgrass were held throughout the life of the Program. From 1995 to 1997, seven regional conferences presented the available information on jointed goatgrass infestations, biology, and control practices. These conferences targeted winter wheat growers in major production areas of the central Great Plains, northern Great Plains, Intermountain West, and Pacific Northwest. In 1999 and 2009, scientific symposia were held in conjunction with the Western Society of Weed Science annual meeting. Tours of research were held in several states each year. Tour attendees included farmers, crop consultants, extension specialists, and media representatives.

Impact: The initial conferences increased producers' awareness of the existing severity and potential future impacts of the jointed goatgrass problem. The conferences also provided producers with the best current information on practices to control jointed goatgrass. Producers used this information to implement control practices and lessen the impact of this invasive weed. At the same time, producers were able to tell researchers where they needed more information on control of jointed goatgrass, helping to establish appropriate research priorities for the Program. The 1999 symposia facilitated the exchange of information among scientists, helping to further define appropriate research. Plot tours and the 2009 symposia further presented research results to a wide audience.

Accomplishment: Multi-topic meetings. As information became available from Program research, it was broadly and quickly disseminated to growers through presentations in a large number of multi-topic meetings. A few of the meetings were Washington State Weed Conference, Oklahoma Ag Expo, National Association of Wheat Growers, Wheat Industry Forum, Wilbur-Ellis Company Growers Meeting, Kansas State University Colby Field Day, and PNW Tri-State Grains Conference.

Impact: Presentations made as part of multi-topic meetings reached many growers, especially producers who might otherwise miss meetings focused solely on jointed goatgrass. These meetings also reached industry personnel, such as agronomy consultants and extension specialists, who further relayed information to additional growers. These presentations speeded the adoption of new and improved jointed goatgrass control practices.

Accomplishment: National JGG website. A website devoted to jointed goatgrass, www.jointedgoatgrass.org, was established in 1996 and continued to be active and maintained at Washington State University beyond the 2009 formal end of the Program. The site was upgraded and expanded several times, and ultimately includes information on identification and biology, genetics, management, current research, past research reports and extension/scientist contact information. The scientific and regional extension bulletins are available for download as PDF files.

Impact: The website provided a mechanism to rapidly transfer new information from the researchers to wheat producers and others interested in jointed goatgrass. For example, in 2003-2004, the site had over 90,000 visits. In the long term, it will likely become the most significant information transfer mechanism.

Accomplishment: Extension publications. Throughout the Program, a variety of extension materials were prepared and distributed. These included a series of brief (4- to 8-page) bulletins on jointed goatgrass ecology, genetics, control tactics, and herbicide resistance management. Numerous popular press articles were prepared and distributed to local, regional, and national publications. Topics included weed control effects from grazing wheat, post harvest weed control, crop rotation, integrated management, and Clearfeld® Imi-Wheat technology. Video, compact disc, slide set, and Power Point presentations were prepared and provided to university extension specialists. Over 1500 "Know and Control Jointed Goatgrass" posters were distributed to grain elevators, certified seed producers and extension offices.

Impact: A broad range of extension materials, widely distributed, helped to maximize information flow to producers and increased the adoption of new and improved weed management practices.

Accomplishment: BMP bulletins. As Program research concluded, a series of detailed (8- to 30-page) BMP (Best Management Practices) bulletins were prepared for the Intermountain West, Southern Great Plains, Central Great Plains, and Pacific Northwest. In the Great Plains over 17,500 BMP bulletins were distributed to farmers in 117 select counties as an insert in the High Plains Journal, the leading regional farm publication. Bulletins were also distributed at field days, no-till conferences, the Oklahoma-Kansas Winter Canola Conference, Montana State University Grassy Weed Workshops and through grain elevators. Content of the Pacific Northwest bulletin was presented as a series of articles in Wheat Life magazine. All four bulletins are available for download at the jointed goatgrass website.

Impact: These bulletins summarized Program research, and provided a single, long-term reference publication for wheat producers in each region. The bulletins stressed a multi-practice approach to weed management, providing insight for control of future invasive species.

V. Brief History of the Program:

In March 1993, members of the Western Regional USDA Multistate Project WRC-77 met during the Western Society of Weed Science annual meeting in Phoenix, AZ with several wheat producers and members of the wheat industry to discuss developing new approaches for controlling jointed goatgrass. In 1993, an informal survey by weed scientists of jointed goatgrass in the western USA revealed that this weed infested nearly 5 million acres of farmland and cost wheat producers $45 million annually as a result of decreased wheat yield and reduced grain quality. At the end of this meeting, an Executive Summary was prepared and sent to state wheat organizations and to the National Association of Wheat Growers. The Executive Summary identified four main areas where work was needed: integrated management, population dynamics, bio-economics and technology transfer. Armed with the Executive Summary, which described the scope of the problem and plans for research to develop new integrated management systems for jointed goatgrass, wheat industry representatives lobbied members of Congress to provide a special grant for research on jointed goatgrass, with the objective of improving weed control. Congress responded by providing $350,000 in FY-1994 for a special grant to USDA-CSREES with Washington State University designated as the lead institution. Through the efforts of state and national wheat organizations, the special grant was renewed each year for 12 more years. During 13 years of funding (FY-1994 through FY-2006), a total of $4,154,419 was appropriated to support research and technology projects on jointed goatgrass in 10 western states.

In October 1993, a National Jointed Goatgrass Symposium was held in Denver, CO to discuss objectives and specific research areas where progress was needed before integrated management plans could be developed. High priority research and technology transfer objectives were identified. Another outcome of this symposium was the formation of the National Jointed Goatgrass Steering Committee, which included representatives of state and federal research organizations, university extension, wheat producer organizations, wheat commissions and USDA-CSREES. The Steering Committee was charged with developing funding priorities each year, providing a peer review system for proposed research and technology transfer projects and to recommend the distribution of grant funds each year. Typically, there were 15 to 20 proposals funded each year. Projects were funded in 10 western states: Washington, Oregon, Idaho, Utah, Montana, Wyoming, Colorado, Nebraska, Kansas, Montana, and Oklahoma. In any given year there were 25 to 30 scientists working on the various projects. The National Steering Committee decided that an Annual Review of progress would be held each year where scientists would present their latest results and answer questions from members of the Steering Committee and other scientists. Beginning in 1996, an Annual Progress Report was published and distributed to all participating scientists and members of the Steering Committee.

Providing extension information to producers was an integral part of the National Jointed Goatgrass Research Program. Activities were initiated at the beginning of the Program with the 1994 proposal "Jointed Goatgrass: A Coordinated Approach to Technology Transfer" and continued beyond the 2009 formal end of the Program with the activation of the website www.jointedgoatgrass.org, maintained at Washington State University. The website contains information in the Annual Progress Reports, the bulletins published by the Program, and a photo gallery. Plans are in place to maintain and update the website through 2012.

Extension activities occurred in three phases. The initial phase focused on increasing producer awareness of jointed goatgrass as an invasive species. The initial phase also provided management information obtained from prior research. The second phase focused on presenting new management and control information as it became available from research activities of the Program. The final phase summarized the Program and earlier research, creating long-term reference guides for producers. The three phases were not

completely independent, with the focus shifting as producer awareness, research information and producer adoption of new management practices evolved over time.
A series of producer conferences were among the earliest activities in the initial phase. In February 1995, conferences were held in Colby, KS, Ogallala, NE, and Sterling, CO. These meetings provided producers information on the extent of jointed goatgrass infestations, the biology and genetics of jointed goatgrass, and potential control strategies as known at that time. In February 1996 similar conferences were held in Lewiston and Pocatello, ID, and Pasco, WA. In January 1997, an additional conference was held in Billings, MT. These meetings reached large numbers of farmers, especially the conferences in Idaho and Washington, which had total attendance of approximately 500 wheat producers.

A full time extension coordinator was also hired during the initial phase. The National Jointed Goatgrass Research Program covered a multi-state area ranging from the southern Great Plains in Oklahoma to the Columbia Plateau in Washington. Given the scope of the Program, a central resource person responsible for information collection and dissemination was required. Extension coordination, which eventually evolved to two regional coordinators, remained important throughout the Program. The first extension coordinator issued numerous press releases and articles in popular agricultural magazines outlining current research projects and early results from these projects. The first website was established at the University of Nebraska in February 1996.

In 1997, a National Symposium on Jointed Goatgrass was held during the National Association of Wheat Growers meeting in Florida. At that meeting, the goals and objectives of the National Jointed Goatgrass Research Program were outlined and some of the early research projects were discussed. In 1998, several presentations on current research and technology transfer activities on jointed goatgrass were given at the National Association of Wheat Growers meeting in San Diego, CA. Field tours were held annually in many states to provide local wheat producers with the latest results of university and federal research programs. In 1999, a national symposium on the National Jointed Goatgrass Program was held during the annual Western Society of Weed Science meeting (papers published in the 1999 Proceedings Western Society of Weed Science, vol. 52).

In 1999, the National Jointed Goatgrass Steering Committee developed a 5-year plan to bring the Program to a conclusion. Included were plans to publish five national bulletins on the state of the science of jointed goatgrass (Jointed Goatgrass: Introduction, Ecology, Genetics, Control Tactics, and Herbicide Resistance Management) and four regional bulletins that would provide guidelines to wheat producers on how to develop integrated management systems to control this weed (Jointed Goatgrass: Best Management Practices---Intermountain Region; Best Management Practices—Central Great Plains; Best

Management Practices—Southern Great Plains; Integrated Management in the Pacific Northwest).

The last year of funding was FY-2006 and all program-supported research was completed by August 31, 2009. A final symposium on the program was held during the Western Society of Weed Science meetings in March 2009. Papers from this meeting were published in the 2009 Proceedings Western Society of Weed Science, vol 62. Also, all project leaders were asked to prepare a poster for the meeting of the Western Society of Weed Science summarizing their research on jointed goatgrass. Abstracts of the contents of these posters were published in the 2009 Proceedings of Western Society of Weed Science and are available at www.jointedgoatgrass.org .

Considering that the program supported research at this scale for 15 years for a total USDA Special Grant expenditure of just over $4 million, the average support for each grant was about $17,000/year. Since the total cost of the research and extension, including support by the home institution of the investigator, investigator salaries, wheat commission support, etc. was much higher, the federal funds were able to leverage and coordinate additional resources at the cooperating institutions. The community organization was able to bring in the needed diversity of research and extension expertise and minimize overlapping research effort and expense. Viable strategies for limiting the spread of jointed goatgrass have been developed and farmers in 10 states are integrating these into their production strategies.

VI. General Operation of Program:

- In 1994, Washington State University hired a research coordinator to oversee the various projects that were funded each year, to prepare an annual progress report, to prepare USDA-CSREES CRIS reports and to plan and organize an annual review of all projects. Each year, about 70 copies of the Annual Progress Report were distributed to scientists and administrators involved in the Program, and to members of the National Jointed Goatgrass Steering Committee.
- The research coordinator worked with staff at Washington State University to establish subcontracts with the 10 western states where research projects and technology transfer activities were conducted. In 1995, a national extension coordinator was also hired to oversee transfer of the new technologies to wheat producers and others in the agricultural community. In 2006, the national extension coordination was reorganized into two regional positions, with one position providing service to the Great Plains and the second position servicing technology needs of the Pacific Northwest and the Intermountain states.
- This Program concluded in August 2009 when the final research projects were completed.

Program agenda that added to its success:

- Selected a problem that was of strong regional interest and included scientists from many states. As a model weed control problem, jointed goatgrass control also had national implications.
- Involved wheat producers and wheat industry people in the initial planning of the program.
- Obtained strong initial and continuing support from state wheat producer organizations and the National Association of Wheat Growers, who were able to sustain funding support for the Program over a 14-year period. This sort of problem requires sustained effort to address.
- Engaged wheat producers and wheat industry people on the National Steering Committee to help focus the Program on finding practical solutions to managing jointed goatgrass in wheat production systems.
- Included technology transfer activities in the initial plan and hired an extension coordinator during the second year of the Program.
- Hired a retired, reputable scientist as the Research Coordinator who was very knowledgeable about jointed goatgrass and winter wheat production and who had excellent organizational skills.
- Held annual review sessions to review progress and final reports and reevaluate progress and priorities. At these reviews, program scientists were required to report their results verbally and answer questions posed by members of the Steering Committee and their colleagues.
- Developed a plan to bring the Program to a conclusion when adequate knowledge for controlling jointed goatgrass was available.
- Published five national and four regional bulletins summarizing the findings of the Program and made these accessible via the Internet so that the best information was available to producers.
- Maintained the website past the formal end of the program to help continue the distribution of research results.
- Program scientists published over 80 peer-reviewed articles.

Changes in operation that would have improved the Program:

- Maintain the same members of the Steering Committee as reviewers of a project throughout the life of the project.
- Provide funding so Steering Committee project reviewers could visit long-term projects at least twice, once during the first year and again during the final year.
- Require that any significant changes to the objectives or procedures be approved by the Steering Committee before changes are made.

- Require that final reports summarizing the significant findings of a project be a condition for future funding. Also, final reports should state whether each hypothesis statement was proven true or false, and should include a summary impact statement. Project reports from scientists should include a section of the scientists' recommended management strategies for growers if the research is providing such information.
- Steering Committee members who are farmers should not be required to be sitting members on a wheat commission or growers' association. Commission and association members have many demands on their time. A qualified farmer recommended by a wheat commission, growers association or university could be more focused on and more involved in the Program.
- Require that steering committee members attend annual reviews and review progress reports and new proposals.
- Extension is most effective for a region when the Extension Coordinator is based in that region. For programs that are nationwide in scope, multiple coordinators are required. Two or three part-time regional Coordinators are more effective than a single full-time national Coordinator.
- It is more important for Extension Coordinators to understand production agriculture in their respective regions than it is for them to have advance science degrees.
- The Extension Coordinator(s) should be responsible to and report to the Program Research Coordinator. If part-time Coordinators otherwise work for research scientists, they should still report to the Program Research Coordinator on matters related to Program Extension.
- The Extension Coordinator(s) should have final responsibility for extension publications issued by the Program.
- Website housing and professional website support should be maintained at one university or research center for the life of the Program.

Unresolved questions and other issues—Future research needs:

- Survey at end of Program to determine if the Program reduced jointed goatgrass.
- What controls seed dormancy in jointed goatgrass? Mechanism of secondary seed dormancy and its role in seed persistence. Maternal effects—which ones are important?
- Understand more fully the fate of seeds/spikelets in soil: microbial seed decay, soil factors, environmental variability, impact of predation. Fate of other seeds in spikelet after the first seed germinates.
- Mechanism of herbicide resistance/tolerance in jointed goatgrass under natural conditions.
- Role of natural population selection for herbicide-resistant jointed goatgrass.
- Identify more fully plant factors that make a wheat variety competitive with jointed goatgrass. Can competitiveness be bred into a wheat variety?

- More long-term, field comparisons of fully integrated management systems with standard systems. Integrated system needs to use all available cultural practices.
- Can viable seed production in jointed goatgrass be predicted using growing degree-days? Can accumulated growing degree-days be used to time herbicide applications and mechanical control practices in the spring to prevent seed production in jointed goatgrass?
- Further refinement of the JGG bio-economic model to integrate cultural practices and crop diversity with management choices and then using the model to manage jointed goatgrass in winter wheat production systems.
- Is it possible to eradicate jointed goatgrass from an infested field?
- Determine if metabolic resistance is a factor in resistance/tolerance of jointed goatgrass to imidazolinone herbicides.
- Determine possible management options after weather factors disrupt integrated weed management system plans.

VII. Funds received and how they were distributed:

During the 13 years of funding (FY-1994 through FY-2006), a total of $4,154,419 was available to support research and technology projects on jointed goatgrass in 10 western states. The largest amount of funding went to integrated management systems (50%) and technology transfer (18%). See Table 1.

Table 1. Allocation of funds among the different types of projects.

Allocation by type of project:	$ Allocated
Integrated management, component and systems research	$1,348,092
Integrated management of imidazolinone-resistant wheat	744,547
Gene flow and genetics	479,379
Basic research (weed biology and physiological studies)	277,522
Bio-economic model development and evaluation	241,500
Biocontrol—Seed decay	79,500
Subtotal	**$3,170,540**
Technology transfer activities:	
Extension coordinators and tech transfer activities	676,630
Bulletins	77,950
Subtotal	**$753,780**
Total for all projects	**$3,924,320 (94.5%)**
Administration of grant	**$230,099 (5.5%)**
(Res. Coordinator salary, operating expenses, travel; Annual Review expense, binding & shipping Progress reports, travel for WSU Administrator, WSU Grant Coordinator)	
Program Total	**$4,154,419**

Table 2. Allocation of Funds by State

State	Research	Tech transfer	Administration	Total
Colorado	$523,716	$122,800*	---	$646,516
Idaho	$348,207	$10,000	---	$358,207
Kansas	$270,792	$181,400*	---	$452,192
Montana	$145,500	$0	---	$145,500
Nebraska	$285,000	$123,500*	---	$408,500
Oklahoma	$285,639	$9,000	---	$294,639
Oregon	$352,186	$6,000	---	$358,186
Utah	$139,000	$2,000	---	$141,000
Washington	$643,000	$297,080*	$230,099**	$1,170,679
Wyoming	$177,500	$2,000	---	$179,000
	$3,170,540	$753,780	$230,099	$4,154,419
	(76%)	(18%)	(6%)	(100%)

* = Most of these funds were used to hire national or regional extension coordinators who had responsibility for more than one state.
** = Administration of Program was handled by Washington State University throughout the life of the Program. Funds include wages for Research Coordinator who had responsibility across all cooperating states. Funds also include operating expenses and travel for Research coordinator; Annual Review expense, binding & shipping Progress reports, travel for WSU Administrator, WSU Grant Coordinator.

VIII. Jointed Goatgrass Related Refereed Publications by Program Scientists:

2012 PUBLICATIONS:

Walters, C. G., F. L. Young, and D. L. Young. 2012. Economics of alternative management practices for jointed goatgrass in winter wheat in the Pacific Northwest. Online. Crop Management doi:10.1094/CM-2012-0227-01-RV.

2011 PUBLICATIONS:

2010 PUBLICATIONS:

Frandrich, L., C. Mallory-Smith and R. Zemetra. 2010. Strategies to minimize the risk of selecting imazamox-resistant jointed goatgrass. EM024E, Washington state University. 16 pages. Pullman, WA.

Perez-Jones, A., B. A. B. Martins and C. A. Mallory-Smith. 2010. Hybridization in a commercial production field between imidazolinone-resistant winter wheat and jointed goatgrass (*Aegilops cylindrica*) results in pollen-mediated gene flow of *Imi1*. Weed Sci. 58:395-401.

Young, F. L., D. A. Ball, D. C. Thill, J. R. Alldredge, A. G. Ogg Jr., and S. Seefeldt. 2010**.** Integrated weed management systems identified for jointed goatgrass (*Aegilops cylindrica*) in the Pacific Northwest. Weed Technology 24:430-439.

2009 PUBLICATIONS:

Schmale, D., T. Peeper and P. Stahlman. 2009. Jointed Goatgrass: Best Management Practices, Southern Great Plains. EM011, Washington State University. 24 pages. Pullman, WA.

Yenish, J., D. Ball, and R. Schirman. 2009. Integrated management of jointed goatgrass in the Pacific Northwest. EM 2042. Washington State University. 16 pages. Pullman, WA.

2008 PUBLICATIONS:

Fandrich, L., C. A. Mallory-Smith, R. S. Zemetra and J. L. Hansen. 2008. Vernalization responses of jointed goatgrass (*Aegilops cylindrica*), wheat and wheat by jointed goatgrass hybrids. Weed Sci. 56:534-542.

Gaines, T., W. B. Henry, P. F. Byrne, P. Westra, S. J. Nissen, and D. L. Shaner. 2008.

Jointed goatgrass (*Aegilops cylindrica*) by imidazolinone-resistant wheat hybridization under field conditions. Weed Sci. 56:32-36.

Kniss, A.R., D. J. Lyon, and S. D. Miller. 2008. Jointed goatgrass management with imazamox-resistant cultivars in a winter wheat-fallow rotation. Crop Sci. 48:2414-2420.

Schmale, Doug, Randy Anderson, Drew Lyon, Bob Klein, Alex Ogg, Jr., Phil Stahlman, Phil Westra, Andrew Kniss, Steve Miller, 2008, Jointed Goatgrass: Best Management Practices, Central Great Plains. EB2008, Washington State University. 30 pp. Pullman, WA.

Yenish, J. P. 2008. Expanded National Jointed Goatgrass Website www.jointedgoatgrass.org to include information on downy brome, volunteer rye, and rattail fescue. Washington State University, Pullman, WA.

2007 PUBLICATIONS:

Anderson, R. L. 2007. A visual guide to help producers manage jointed goatgrass. Weed Technol. 21:275-278.

Carter, A. H., J Hansen, T. Koehler, D. C. Thill, and R. S. Zemetra. 2007. The effect of imazamox application timing and rate on imazamox resistant wheat cultivars in the Pacific Northwest. Weed Technol. 21:895-899.

Quinn, M., D. Morishita, J. Evans, R. Whitesides, and T. White. 2007. Jointed Goatgrass: Best Management Practices (BMP) Intermountain Region. Washington State University Extension Bulletin EB2003. 8 pp. Pullman, WA.

Zemetra, R. S., M. Rehman, A. Perez-Jones, J. L. Hansen, C. J. W. Watson, C. A. Mallory-Smith, and O. Riera-Lizarazu. 2007. Introgression of genes between wheat (*Triticum aestivum*) and jointed goatgrass (*Aegilops cylindrica*). PAG XV Abstracts pg. 69.

2006 PUBLICATIONS:

Ghandi, H., C. Mallory-Smith, C. Watson, M.I. Vales, N. Mori, R.S. Zemetra, and O. Riera-Lizarazu. 2006. Hybridization between wheat and jointed goatgrass (*Aegilops cylindrica*) under field conditions. Weed Sci : 54:1073-1079.

Perez-Jones, A., C. A. Mallory-Smith, J. Hansen, and R. S. Zemetra. 2006. Introgression of an imidazolinone-resistance gene from winter wheat (*Triticum aestivum* L.) into jointed goatgrass (*Aegilops cylindrica* Host). Theoretical and Applied Genetics. 114: 177-186.

Perez-Jones, A., C. A. Mallory-Smith, O. Riera-Lizarazu, C. J. Watson, Z. Wang, M. Rehman, and R. S. Zemetra. 2006. Introgression of a foot rot resistance gene from winter wheat (*Triticum aestivum*) into jointed goatgrass (*Aegilops cylindrica*). Crop Sci. 46:2155-2160.

Quinn, M. P., D. W. Morishita and W. J. Price. 2006. Determining physiological maturation of jointed goatgrass (*Aegilops cylindrica*). Weed Technol. 20:921-933.

Rehman, M., J.L. Hansen, J. Brown, W. Price, R.S. Zemetra, and C. Mallory-Smith. 2006. Effect of wheat genotype on the phenotype of wheat (*Triticum aestivum*) x jointed goatgrass (*Aegilops cylindrica*) hybrids. Weed Sci. 54: 690-694.

Rehman, M., J. Hansen, and R.S. Zemetra. 2006. Hybrids and amphidiploids of *Aegilops cylindrica* and *Triticum aestivum*; production, morphology and fertility. Pak. J. Biol. Sci. 9: 1563-1566.

Zemetra, Robert, Carol Mallory-Smith and Tony White. 2006. Jointed Goatgrass: Genetics. National Jointed Goatgrass Research Program. Washington State University Extension Service. EB1934. 4 pages. Pullman, WA.

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Ghandi, H., M. I. Vales, C. Watson, C. Mallory-Smith, N. Mori, M. Rehman, R. S. Zemetra, and O. Riera-Lizarazu. 2005. Chloroplast and nuclear microsatellite analysis of *Aegilops cylindrica*. Theoretical and Applied Genetics 111:561-572.

Hanson, B. D., C. A. Mallory-Smith, B. Shafii, D. C. Thill, and R. S. Zemetra. 2005. Pollen-mediated gene flow from blue aleurone wheat to other wheat cultivars. Crop Sci. 45:1610-1617.

Hanson, B. D., C. A. Mallory-Smith, W. J. Price, B. Shafii, D. C. Thill, and R. S. Zemetra. 2005. Interspecific hybridization: Potential for movement of herbicide resistance from wheat (*Triticum aestivum*) to jointed goatgrass (*Aegilops cylindrica*). Weed Technol. 19:674-682.

Wicks, G., R. Anderson, T. White, P. Stahlman, and D. Morishita. 2005. Jointed Goatgrass: Control Tactics. National Jointed Goatgrass Research Program. Washington State University Extension Service. EB1935. 8 pages.

2004 PUBLICATIONS

Anderson, R. L., D. Hanavan, and A. G. Ogg, Jr. 2004. Developing national research teams: a case study with the Jointed Goatgrass Research Program. Weed Technol. 18:1143-1149.

Geier, P. W., P. W. Stahlman, A. D. White, S. D. Miller, C. M. Alford and D. J. Lyon. 2004. Imazamox for winter annual grass control in imidazolinone-resistant winter wheat. Weed Technol. 18:924-930.

Kroiss, L. J., P. Tempalli, J. L. Hansen, M. I. Vales, O. Riera-Lizarazu, R. S. Zemetra and C. A. Mallory-Smith. 2004. Marker-assisted retention of wheat chromatin in wheat (*Triticum aestivum*) by jointed goatgrass (*Aegilops cylindrica*) backcross derivatives. Crop Sci. 44:1429-1433.

Rainbolt, C. R., D. C. Thill, J. P. Yenish and D. A. Ball. 2004. Herbicide-resistant grass weed development in imidazolinone-resistant wheat: weed biology and herbicide rotation. Weed Technol. 18:860-868.

Rainbolt, C., D. Ball, D. Thill, and J. Yenish. 2004. Management strategies for preventing herbicide-resistant grass weeds in Clearfield Wheat systems. Univ. of Idaho Coop. Ext. Bull. PNW-0572. 8 pp.

Stone, A. E. and T. F. Peeper. 2004. Characterizing jointed goatgrass (*Aegilops cylindrica*) x winter wheat hybrids in Oklahoma. Weed Sci. 52:742-745.

White, A. D., P. W. Stahlman, and F. E. Northam. 2004. Impact of integrated management systems on jointed goatgrass (*Aegilops cylindrica*) populations. Weed Sci. 52:1010-1017.

Yenish, J. P. and F. L. Young. 2004. Winter wheat competition against jointed goatgrass (*Aegilops cylindrica*) as influenced by wheat plant height, seeding rate, and seed size. Weed Sci. 52:996-1001.

<u>2003 PUBLICATIONS:</u>

Pester, T.A., S. M. Ward, P. Westra, and S. J. Nissen. 2003. Genetic diversity of jointed goatgrass (*Aegilops cylindrica*) determined with RAPD and AFLP markers. Weed Sci. 51:287-293.

White, T. and P. Stahlman. 2003. Control of jointed goatgrass using best management practices. The 6th Annual National Wheat Industry Forum Proceedings, Albuquerque, NM. National Association of Wheat Growers, Wheat Industry Resource Committee. P.22-24.

Young, F. L., J. P. Yenish, D. L. Walenta, D. A. Ball and J. R. Alldredge. 2003. Spring-germinating jointed goatgrass (*Aegilops cylindrica*) produces viable spikelets in spring-seeded wheat. Weed Sci. 51:379-385.

<u>2002 PUBLICATIONS:</u>

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Morrison, L. A., L. C. Cremieux and C. A. Mallory-Smith. 2002. Infestations of jointed goatgrass and its hybrids in wheat in Oregon. Weed Sci. 50:737-741.

Morrison, L. A., O. Riera-Lizarazu, L. Crenieux and C. A. Mallory-Smith. 2002. Jointed goatgrass (*Aegilops cylindrica* Host) x wheat (*Triticum aestivum* L) hybrids: Hybridization dynamics in Oregon wheat fields. Crop Sci. 42:1863-1872.

Morrison, L. A., O. Riera-Lizarazu, M. I.Vales, L. Cremieux, R. S. Zemetra, J. Hansen, and C. Mallory-Smith. 2002. Gene diversity and gene flow in the crop-weed complex of wheat (*Triticum aestivum* L.) and jointed goatgrass (*Aegilops cylindrica* Host). *4th International Triticeae Symp.* pgs 125-130.

Riera-Lizarazu, O., M. I. Vales, L. A. Morrison, R. S. Zemetra, D. Morishita, J. Hansen, and C. Mallory-Smith. 2002. Gene flow and hybridization between wheat (*Triticum aestivum* L.) and its wild weedy relative jointed goatgrass (*Aegilops cylindrica* Host). *4th International Triticeae Symp.* pgs 301-205.

Walenta, D. L., J. P. Yenish, F. L. Young and D. A. Ball, 2002. Vernalization response of plants grown from spikelets of spring and fall cohorts of jointed goatgrass. Weed Sci. 50:461-465.

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Young, F.L., D. A. Ball, D. Thill, J. P. Yenish, and A. R. Alldredge. 2002. Integrated management of jointed goatgrass (*Aegilops cylindrica*) in Pacific Northwest dryland cropping systems. Pages 284-286 in H. S. Jacob, J. Dodd and J. H. Moore, eds., Weeds: Threats Now and Forever? Proc. 13th Australian Weeds Conference, Perth, Western Australia.

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