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Spring-germinating jointed goatgrass (*Aegilops cylindrica*) produces viable spikelets in spring-seeded wheat

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The most common strategy recommended for management of jointed goatgrass infestations is to rotate from winter wheat to a spring crop for several years. A field study was conducted at three locations in 1998 and 1999 to determine the effects of spring seeding date on the ability of jointed goatgrass to flower and produce viable seed in the presence or absence of spring wheat and to determine the effect of jointed goatgrass competition and crop seeding date on spring wheat grain yield. Spring wheat was seeded on four dates at each location in both hand-sown and natural jointed goatgrass infestations. Jointed goatgrass plants from hand-sown spikelets flowered and developed spikelets on all seeding dates except the last; viable seed was produced on the two earliest seeding dates. Jointed goatgrass plant densities from natural infestations were from 1 to 12 plants m^{-2}, and spikelet production ranged from 0 to 480 spikelets m^{-2}. Natural jointed goatgrass infestations produced spikelets containing viable seed on all seeding dates at one location in 1998, the driest location. Spring wheat yield was not affected by jointed goatgrass competition; however, jointed goatgrass spikelet production was reduced by spring wheat competition compared with that of monoculture jointed goatgrass. The last seeding date of spring wheat was associated with 51% less crop yield compared with the recommended seeding date. The decision to manage jointed goatgrass infestations with a spring crop rotation should consider delayed seeding dates to minimize viable spikelet production by spring-germinating jointed goatgrass; however, the cost of this decision may include grain yield reduction.

Nomenclature: Jointed goatgrass, *Aegilops cylindrica* Host. AEGCY; spring wheat, *Triticum aestivum* L. 'Penewawa'.

Key words: Natural infestation, hand-sown infestation, cultural control, seeding date, vernalization.

Jointed goatgrass is a winter annual grass weed that infests more than 2,000,000 ha of wheat in the Pacific Northwest, Great Plains, and Intermountain regions of the United States (Ogg 1993). Jointed goatgrass is related to winter wheat and interferes with winter wheat growth and development, and reduces grain yield and quality (Anderson 1993; Donald and Ogg 1991; Fleming et al. 1988; Rydrich 1983). Practices that contribute to the increased establishment of jointed goatgrass in winter wheat production areas include production of continuous winter wheat, use of less competitive semidwarf wheat varieties, increased use of nitrogen fertilizers, and conservation tillage systems. Harvested winter wheat grain contaminated with jointed goatgrass spikelets increases the dockage penalty and reduces the market price growers receive for their grain. In addition, growers cannot produce grain for seed certification if jointed goatgrass is present in the field or harvested crop.

Jointed goatgrass has several traits that enable it to establish and compete successfully with winter wheat. Therefore, most of the weed–crop studies conducted with jointed goatgrass have included winter wheat. Areas of study include genetics (Seefeldt et al. 1998; Snyder et al. 2000; Zemetra et al. 1998), morphology (Dotray and Young 1993), and biology (Fleming et al. 1988; Mesbah and Miller 1999; Young et al. 1999).

Jointed goatgrass continues to be a problem in winter wheat because herbicides are not available to selectively control it in the crop. Resistance to imazamox, an imidazolinone, has been incorporated into a winter wheat variety. This technology controls jointed goatgrass effectively and does not kill winter wheat (Ball et al. 1999; Newhouse et al. 1992). However, imazamox-resistant winter wheat is not available commercially to all growers in all regions. For most growers, control is limited to cultural methods such as planting spring crops for several years, using short crop rotations, burning stubble after harvest, moldboard plowing to bury seed below the depth of emergence, fertilizer placement, and delayed seeding in the fall (Anderson 1998; Donald and Ogg 1991; Young et al. 1990, 1999). These production options are not always feasible, economical, or environmentally sound because of weather and market dynamics. Fall field burning is an economical and effective means of managing small infestations of jointed goatgrass (Young et al. 1990), but laws may restrict burning as an agricultural tool. When fall moisture is adequate, delaying fall seeding of winter wheat would allow winter annual weeds to emerge and be killed by herbicides or tillage before seeding. However, delayed seeding in the fall can reduce grain yields (Anderson 1998; Wicks 1984), and the practice is not needed in dry years because weeds do not emerge.

One commonly recommended strategy for jointed goatgrass management is to rotate from winter to spring wheat for several years. Tillage and herbicide applications in the fall and spring before crop seeding destroy jointed goatgrass

Table 1. Spring wheat (*Triticum aestivum* L.) seeding dates at Lind, WA, Pendleton, OR, and Pullman, WA.

Seeding date[a]	Seeding date					
	Lind, WA		Pendleton, OR		Pullman, WA	
	1998	1999	1998	1999	1998	1999
1	March 4	March 4	March 25	March 16	March 30	April 6
2	March 17	March 18	April 8	March 31	April 15	April 16
3	March 30	March 31	April 23	April 14	April 30	April 30
4	April 15	April 13	May 6	April 28	May 15	May 14

[a] The recommended or second seeding dates were March 15 at Lind, March 30 at Pendleton, and April 15 at Pullman.

plants and deplete the soil of jointed goatgrass spikelets over time. Weed populations tend to be associated with crops of similar life cycles; therefore, weed–crop associations can be disrupted by planting crops with different life cycles (Blackshaw et al. 1994). However, in the Pacific Northwest, spring cereal crops often yield less and are less profitable than winter wheat (Young et al. 2000). Nevertheless, when farmers have grown spring wheat, they and researchers have become aware of the occasional presence of jointed goatgrass.

Jointed goatgrass germinates, establishes, and flowers in the spring of the year if vernalization conditions are met (Donald 1984). However, production of viable jointed goatgrass seed in spring crops has not been investigated. If viable seed is produced by spring-germinating jointed goatgrass in a spring cereal crop, the soil seed bank may be partially replenished to provide carryover seed to subsequent crops. Spring wheat grain yield and quality may be reduced because of competition with spring-germinating jointed goatgrass. Delayed seeding of spring wheat may avoid crop yield losses, contaminated grain, and weed seed production by jointed goatgrass. However, in the Pacific Northwest, spring grain yield and quality may be reduced by delayed seeding (Ciha 1983). In addition, long-term spring crop rotations may select a jointed goatgrass population adapted to spring emergence or one that produces seed that remains dormant for longer periods of time.

The objectives of this study were (1) to determine the effects of spring seeding date on the ability of jointed goatgrass to flower and produce viable seed in the presence or absence of spring wheat, and (2) to determine the effect of jointed goatgrass competition and crop seeding date on spring wheat grain yield.

Materials and Methods

A study, with two experiments at each location, was conducted in 1998 and 1999 at Lind, WA, Pendleton, OR, and Pullman, WA, where the long-term average annual precipitation is 235, 420, and 560 mm, respectively. Predominant crop rotations were winter wheat–fallow at Lind, winter wheat–spring cereal–fallow at Pendleton, and winter wheat–spring barley–spring legume at Pullman. Soil type at the Lind site was a Shano silt loam (coarse silty, mixed mesic Andic Haplustoll) with 0.8% organic matter and pH 6.2. Soil type at Pendleton was a Walla Walla silt loam (mixed mesic Typic Haploxerolls) with 1.8% organic matter and pH 5.5. Soil type at Pullman was a Palouse silt loam (fine silty, mixed mesic Typic Haploxerolls) with 3.6% organic matter and pH 5.3.

An experiment with a hand-sown infestation of jointed goatgrass was established at each location in a fallow field not previously infested with jointed goatgrass. Spikelets that were collected in 1994 from plants at the U.S. Department of Agriculture Palouse Conservation Field Station in Pullman, WA, were broadcast by hand at a rate of 160 spikelets m^{-2} immediately before seeding spring wheat at each planting date (Table 1), to ensure a jointed goatgrass population that was exposed only to spring-time growing conditions. Spikelets had been stored dry in a nonheated shed before seeding. Spikelets were partially incorporated into the soil by seeding spring wheat with a double-disk drill. In addition to crop seeding dates, the crop–weed treatments in this experiment were monoculture jointed goatgrass, monoculture spring wheat, and spring wheat with jointed goatgrass.

Another experiment with a natural infestation of jointed goatgrass was established at each location in a fallow field. Treatments were initiated at the same time as for the above experiment (Table 1) and included seeding dates, monoculture jointed goatgrass, and spring wheat with jointed goatgrass.

Fertilizer was applied in the fall at each location based on soil test recommendations. At Lind, liquid fertilizer was applied with shanks to a soil depth of 12 to 15 cm at a rate of 56 kg N ha^{-1}. At Pendleton, dry fertilizer was applied at a rate of 48 kg N ha^{-1} with a granular spreader. At Pullman, liquid fertilizer was applied with shanks to a soil depth of 10 to 12 cm at a rate of 100 kg N ha^{-1}. At seeding, an additional 18 kg N ha^{-1} and 22 kg P_2O_5 ha^{-1} were placed in the seed row using the drill. Approximately 2 wk before the first seeding date (Table 1) at each location, 0.42 kg ae ha^{-1} glyphosate with 0.25% (v/v) nonionic surfactant was applied to both the natural and the hand-sown areas. On each seeding date, the seedbed was prepared by cultivation, and Penewawa soft white spring wheat was planted 2 cm deep in an 18-cm row spacing using a 2.4-m-wide double-disk drill. Seeding rates at Lind, Pendleton, and Pullman were 65, 85, and 105 kg ha^{-1}, respectively. At each location, the first seeding date was approximately 2 wk before the recommended spring wheat seeding (Table 1). Winter wheat is the major crop grown in these regions; therefore, information was not available for optimum spring wheat seeding dates for modern varieties. Thus, dates were based on grower and research scientist experience.

Spring wheat seeding dates ranged from early March to mid-May depending on location (Table 1). At Lind and Pullman, the seeding date for each respective seeding interval was similar between years. At Pendleton, seeding intervals were about 9 d earlier in 1999 than the respective intervals in 1998 because of drier soil conditions on the first seeding date in 1999. Jointed goatgrass and spring wheat seeding began approximately on March 1 and ended in mid-April each year at Lind. The primary factor dictating spring seeding at Lind was soil temperature. Location is subject to low temperatures in March and early April. In 1999, soils were frozen to a depth of 2.5 cm on the first seeding date, and the site was cultivated three times to prepare a seed bed. In contrast, soil moisture determined the initial seeding dates at Pendleton and Pullman.

During the growing season, broadleaf weeds were controlled with 0.38 kg ai ha^{-1} bromoxynil plus 0.38 kg ae ha^{-1} MCPA with 0.25% (v/v) nonionic surfactant applied once at each location. In 1999 at the Pullman site, wild oat (*Avena fatua* L.) was controlled with 0.7 kg ai ha^{-1} difenzoquat; additional hand weeding of wild oat was necessary in both years.

For both experiments at each location, three 0.25-m^2 quadrats were established 2 wk after each seeding date in each plot to determine emergence, biomass, and yield of spring wheat and jointed goatgrass. Plot size in the hand-sown jointed goatgrass infestation was 2.4 by 9.1 m, whereas in the natural jointed goatgrass infestation, plot size was 2.4 by 15.2 m. At spring wheat maturity, jointed goatgrass spikes and spikelets were counted in each quadrat and harvested by clipping at the base of each spike. The remainder of jointed goatgrass aboveground biomass was collected by clipping plants at the soil surface for determination of dry biomass production. At maturity, spring wheat was hand harvested in each quadrat, dry-stored, and threshed with a stationary thresher. Wheat yield and 1,000-kernel weight were measured from clean grain samples. Dockage was based on a ratio of jointed goatgrass spikelet dry weight to spring wheat clean grain dry weight. Jointed goatgrass spikelets collected from field studies were dry-stored for 1 yr to overcome postharvest dormancy. The jointed goatgrass spikelets were tested for germination by placing spikelets on moistened (deionized water) germination paper. The germination paper was loosely rolled, bound with a rubber band (Yenish et al. 1992) and placed in glass beakers on a lab bench at room temperature (18 C). Caryopses within spikelets were considered germinated if a radicle was visible posterior to the glumes. Percent germination was determined 7, 14, and 21 d after the spikelets were placed on the paper.

Before each seeding date in the natural jointed goatgrass experiment at each location, soil samples were collected from each plot to determine jointed goatgrass spikelet density in the soil. In 1998, 15 soil cores (2-cm diameter by 15-cm depth) were collected randomly from within each plot and bulked together. In 1999, four soil cores (7-cm diameter by 15-cm depth) were collected randomly from within each plot. Soil samples were frozen to prevent seed germination. Soil samples were removed from the freezer 6 mo after the final collection date and allowed to thaw overnight at room temperature on a greenhouse bench. Jointed goatgrass spikelets were extracted with a water-spray system (Kovach et al. 1988) and expressed as spikelets per square meter, 15 cm deep.

Both experiments were conducted as a randomized complete block design with two factors, crop–weed treatments and seeding date treatments, and four replications. Analysis of variance was used (SAS 1999, Proc GLM) for response variables where the assumptions of normality and homogeneity of variance were satisfied, either on the original scale of measurement or after a suitable transformation. Generalized linear model methodology (SAS 1999, Proc GENMOD) was used with a negative binomial distribution for count data where there were many zero values as well as large counts. Dunnett's methods or contrasts with Bonferroni-adjusted significance levels were used to identify significantly different factor levels (Kuehl 2000). Simple effects of seeding date and crop–weed treatments were examined when a significant interaction existed between these factors. Because there were significant differences in error mean squares between years and locations, separate analyses were conducted for each year by location combination. For all data, treatments are compared with the second seeding date because that date is the standard or recommended target date for spring wheat planting.

Table 2. Monthly precipitation and long-term averages for the 1998 and 1999 spring wheat (*Triticum aestivum* L.) growing season at Lind, WA, Pendleton, OR, and Pullman, WA.

	Precipitation								
	Lind			Pendleton			Pullman		
Month	1998	1999	Average[a]	1998	1999	Average[a]	1998	1999	Average[a]
	mm								
March	17	13	22	36	31	51	29	21	50
April	3	8	19	33	25	41	22	9	40
May	38	15	22	79	42	48	86	20	39
June	2	13	20	13	15	29	18	32	38
July	12	3	7	5	1	10	36	4	13
Total	72	52	90	166	114	179	191	86	180

[a] Long-term average monthly precipitation based on 70-, 20-, and 70-yr averages at Lind, Pendleton, and Pullman, respectively.

Results and Discussion

Precipitation

Precipitation varied by location; however, all three sites were drier than normal in 1999 (Table 2). During 1999, precipitation at Pendleton and Pullman was 36 and 52% less, respectively, than the long-term average. Lind precipitation was 20 and 42% less than the long-term average in 1998 and 1999, respectively. The frequency of precipitation at each location for both years varied. In both years, monthly precipitation was greater during May than in March and April at Pendleton and greater during May than in April at Pullman. Less precipitation was received in April than in March in each year at all locations.

Jointed Goatgrass Density and Reproduction

Spring wheat emergence and early growth were greater than those of jointed goatgrass in either hand-sown or natural infestations (data not shown). Jointed goatgrass plants from hand-sown spikelets occurred on all seeding dates and at all locations (Table 3). Plant density ranged from 20 to 30% of the sown spikelets; however, in 1999 at Lind, plant density ranged from 2 to 7% of the sown spikelets. In contrast, in 1998 at Pendleton, establishment ranged from 61 to 83% of the sown spikelets. Because spikelets were not exposed to long periods of low temperature before sowing, secondary dormancy (C. C. Baskin and J. M. Baskin 1985)

TABLE 3. Jointed goatgrass (*Aegilops cylindrica* Host. AEGCY) plant density in hand-sown infestations as affected by seeding date and spring wheat (*Triticum aestivum* L.) competition at Lind, WA, Pendleton, OR, and Pullman, WA, in 1998 and 1999. Data were collected at crop maturity for each year-location. Seeding dates are shown in Table 1.

	Plant density					
	Lind		Pendleton		Pullman	
Main effect	1998	1999	1998	1999	1998	1999
	No. plants m^{-2}					
Seeding date[a]						
1	38*	12	115	29	15	47
2	24	7	98	33	12	51
3	16	9	115	44	18	50
4	26	5	133*	48	41*	42
Competition[b]						
AEGCY with wheat	22	7	113	37	17+	52
AEGCY without wheat	29	9	118	40	34	44

[a] Seeding date averaged over competition. An asterisk (*) denotes the means within a column that differ from that for the second seeding date, as determined by the Dunnett method ($P < 0.05$).

[b] Competition averaged over seeding date. A plus (+) denotes the means within a column that differ between treatments, as determined by generalized linear model contrasts ($P < 0.05$).

would not have been induced. In natural infestations of jointed goatgrass, plant density was 1 plant m^{-2} or less across seeding dates, years, and locations, even though the estimated soil seed bank ranged from 100 to 830 spikelets m^{-2} across locations (data not shown). Many jointed goatgrass plants in the natural infestation did not emerge in spring because of secondary dormancy, or they were killed preplant by either a nonselective herbicide or tillage operations.

Jointed goatgrass emergence in hand-sown infestations occurred 10 to 14 d after spring wheat emergence (data not shown). The delay in jointed goatgrass emergence was attributed to planting spring wheat in adequate soil moisture, whereas jointed goatgrass spikelets were sown on the soil surface and lightly incorporated in the top 1 cm of soil, which was dry. There was no interaction between seeding date and competition for jointed goatgrass density in the hand-sown infestations. Seeding date and competition seldom influenced jointed goatgrass plant density (Table 3). In 1998, the highest density of jointed goatgrass occurred on the first planting date at Lind and the last planting date at Pendleton and Pullman. At Lind, soil moisture was more limiting and the pattern of rainfall less favorable for emergence of late-seeded jointed goatgrass than at the other two locations (Table 2). Climatic and soil conditions at Lind may have increased the rate at which soil surface moisture was lost, which contributed to decreased jointed goatgrass densities with later seeding. Thus, establishment was affected more by environmental factors than simply by date of seeding. In addition, there was more rainfall at Pendleton and Pullman than at Lind after spring wheat seeding. In 1999, jointed goatgrass densities within a location were similar regardless of seeding date. The only incidence of spring wheat affecting jointed goatgrass plant density was in 1998 at Pullman, when weed density was 50% less with wheat than without wheat (Table 3).

Spring-germinating jointed goatgrass plants in both hand-sown and natural infestations produced spikes, with the highest number of spikes produced on the earliest seeding date (data not shown). During the highest production year, in the hand-sown infestation, 210, 9, and 19 spikes m^{-2} were produced at Lind, Pendleton, and Pullman, respectively, on the first seeding date (data not shown). In contrast, naturally infested jointed goatgrass spike production was highly variable, but plants produced some spikes at Lind and Pullman regardless of seeding date. It is not known whether vernalization of the imbibed seed occurred or if vernalization was necessary for spring-germinating jointed goatgrass to produce spikes in the natural infestation experiment. Winter annual grass species, such as jointed goatgrass and winter wheat, can be vernalized as imbibed seed or as seedlings (Chouard 1960; Donald 1984). A recent growth chamber–greenhouse study indicated that jointed goatgrass can produce spikes in the absence of vernalizing conditions but requires more than 165 d to do so (Walenta et al. 2002). That study suggested that jointed goatgrass may be described as a facultative winter annual rather than a strict winter annual. Results from hand-sown infestations in this study are consistent with results from previous research in Colorado that indicated that jointed goatgrass planted after May did not flower during the subsequent summer (Donald 1984). Vernalization requirements were met possibly on the earlier seeding dates but not on the later seeding dates. Also, spike production may have been limited by factors such as decreased precipitation after seeding at later dates. Spike production in both infestations was not affected by competition with spring wheat across years or locations, except for the hand-sown experiment at Lind each year, where jointed goatgrass grown alone produced between four and five times more spikes than did jointed goatgrass grown with spring wheat (data not shown).

In the hand-sown jointed goatgrass infestation, there was a seeding date by competition interaction for spikelet production at Lind in 1998 and at Pendleton in 1999 (Table 4). In these two instances, spikelet production for the earliest seeding date was about 75% less when jointed goatgrass competed with wheat than when it was grown alone. Spikelet production was rarely influenced by competition during the remaining three dates of seeding. Seeding spring wheat on the recommended date of seeding (the second seeding date at a location) either reduced or eliminated spikelet production compared with seeding spring wheat on the earliest date. In those instances where the spikelets were produced on the second seeding date, delayed wheat seeding until the third and fourth date further reduced spikelet production compared with wheat seeding on the second date. Spikelet production on the third seeding date was observed in only two of the six year-locations, and no production was observed on the last seeding date within a location.

For the natural infestation, spikelet number varied greatly among years, locations, and seeding dates (Table 5). A significant seeding date by competition interaction occurred in 1999 at Lind, where no spikelets were produced by jointed goatgrass for the last three seeding dates in wheat or the last two dates when grown alone. When averaged over competition, spikelet production was similar regardless of seeding date at Lind in 1998 and at Pendleton in 1998 and 1999.

A seeding date by competition interaction for percent vi-

TABLE 4. Jointed goatgrass (*Aegilops cylindrica* Host.) spikelet production in hand-sown infestations as affected by seeding date or spring wheat (*Triticum aestivum* L.) competition (or both) at Lind, WA, Pendleton, OR, and Pullman, WA, in 1998 and 1999. Data were collected at crop maturity for each year-location. Seeding dates are shown in Table 1.

	Hand-sown spikelet production							
	Lind			Pendleton			Pullman	
	1998[a]				1999[a]			
Seeding date	With wheat	Without wheat	1999	1998	With wheat	Without wheat	1998	1999
	No. m^{-2}							
1	230*[b] a	972* b	1,868*	22*	30* a	116* b	< 1	148*
2	16 a	0 a	160	0	5 a	0 b	0	9
3	0* a	0 a	5*	0	0* a	0 a	0	2*
4	0* a	0 a	0*	0	0* a	0 a	0	0*

[a] A significant treatment interaction occurred; means followed by the same letter do not differ between competition treatments (with or without spring wheat), as determined by generalized linear model contrasts ($P < 0.05$).
[b] An asterisk (*) denotes the means within a column that differ from that for the second seeding date as determined by generalized linear model contrasts ($P < 0.05$).

able spikelets occurred in both years at Lind in the hand-sown infestation, in 1999 at Pullman in the hand-sown infestation, and in 1999 at Lind in the natural infestation (Table 6). For other years and locations, data were averaged over competition treatments for each seeding date. It is not known why in three out of four year-locations, jointed goatgrass produced a greater percentage of spikelets containing viable seed when grown in competition with than without spring wheat on the first seeding date. Even though percent spikelet viability was greater in jointed goatgrass grown in spring wheat in most of these instances, the total number of seed produced was generally less. For example, at Lind in 1998, 230 and 972 spikelets were produced by jointed goatgrass grown with and without spring wheat, respectively (Table 4); viable seed number was 131 and 292 seed for jointed goatgrass grown with and without spring wheat, respectively (data not shown). Viable seed was produced on the second seeding date at Lind and Pullman in both the hand-sown and natural infestations (Table 6). This result has important management implications because the second seeding date at each location was considered the recommended target date for spring wheat seeding to obtain optimal grain yield. However, at Lind in 1998 and Pullman in 1999, jointed goatgrass grown in wheat produced less viable seed on the second seeding date than on the first seeding date in the hand-sown infestation. Spikelets with viable seed were also lower in wheat for the second planting date than for the first planting date at Lind in 1999 in the natural infestation.

In contrast to Lind and Pullman, no viable seed was produced at Pendleton in either year in the natural infestation (Table 6). In the hand-sown infestation, viable seed was produced only on the first seeding date. Data for the third and fourth seeding dates were not statistically analyzed because of the lack of spikelet production in many treatments (Tables 4 and 5). Other than at Lind in 1998, viable seed was not produced after the second seeding date.

These results indicate that jointed goatgrass emerging in spring from a natural infestation can produce germinable seed, but seed production can be reduced or eliminated by delaying spring wheat seeding. Results from the hand-sown infestations indicate that springtime conditions may be sufficient to vernalize jointed goatgrass spikelets, allowing them to produce viable seed before spring wheat maturity. Consequently, if control is not possible in spring crops, the benefits of rotation to a spring crop are partially negated by spikelet production of jointed goatgrass in early-seeded fields.

TABLE 5. Jointed goatgrass (*Aegilops cylindrica* Host.) spikelet production in natural infestations as affected by seeding date or spring wheat (*Triticum aestivum* L.) competition (or both) at Lind, WA, Pendleton, OR, and Pullman, WA, in 1998 and 1999. Data were collected at crop maturity for each year-location. Seeding dates are shown in Table 1.

	Natural spikelet production						
	Lind			Pendleton		Pullman	
		1999[a]					
Seeding date	1998	With wheat	Without wheat	1998	1999	1998	1999
	No. m^{-2}						
1	8	64*[b] a	250 a	< 1	—[c]	44*	480
2	13	0 a	438 a	3	—	14	112
3	12	0 a	0* a	0	—	0	130*
4	15	0 a	0* a	0	—	0	47*

[a] A significant treatment interaction occurred; means followed by the same letter do not differ between competition treatments (with or without spring wheat), as determined by generalized linear model contrasts ($P < 0.05$).
[b] An asterisk (*) denotes the means within a column that differ from that for the second seeding date, as determined by generalized linear model contrasts ($P < 0.05$).
[c] A dash (—) denotes that either no plants or no spikes were produced, and therefore no spikelets were produced.

Spring Wheat Yield

Seeding date was the most critical factor affecting spring wheat yield in both experiments (Table 7). As with jointed goatgrass, spring wheat yields for the first, third, and fourth seeding dates were compared with yield for the recommended or second seeding date. There was no significant date by competition interaction, and the simple effect of competition was not significant. Spring wheat yield was similar for the two earliest seeding dates within a year at each location, with two exceptions. For the 2-yr study there was

Table 6. Percentage of jointed goatgrass (*Aegilops cylindrica* Host.) spikelets containing viable seed in hand-sown and natural infestations as effected by seeding date or spring wheat (*Triticum aestivum* L.) competition (or both) at Lind, WA, Pendleton, OR, and Pullman, WA, in 1998 and 1999. Data were collected at crop maturity for each year-location. Seeding dates are shown in Table 1.

	Spikelets with viable seed																
	Hand-sown infestation									Natural Infestation							
	Lind				Pendleton		Pullman			Lind			Pendleton		Pullman		
	1998[a]		1999[a]					1999[a]			1999[a]					
Seed-ing date	With wheat	Without wheat	With wheat	Without wheat	1998	1999	1998	With wheat	Without wheat	1998	With wheat	Without wheat	1998	1999	1998	1999
	% spikelets																
1	57*[b] b	30* a	81* a	75* a	2	12	9	62* b	13 a	29	71* a	23 a	0	—[c]	45	23
2	7 a	0 a	64 b	24 a	—	0	—	8 a	0 a	66	0 a	44 a	0	—	10	19
3	—		0		—	—	—	0		49	—		—	—	—	1
4	—		—		—	—	—	—		45	—		—	—	—	0

[a] A significant treatment interaction occurred; means followed by the same letter do not differ between competition treatments (with or without spring wheat), as determined by generalized linear model contrasts ($P < 0.05$).

[b] An asterisk (*) denotes the means within a column that differ from that for the second seeding date, as determined by generalized linear model contrasts ($P < 0.05$).

[c] A dash (—) denotes that either no plants or no spikes were produced and therefore no spikelets were produced.

only one environment, the natural infestation at Lind in 1999, in which grain yield was greater on the first seeding date than on the second. Compared with grain yields on the recommended seeding date, yields were typically less on the last seeding date (Table 7). This yield reduction was generally attributed to decreased precipitation and the shortened growing season after late seeding. In the hand-sown infestation, yield was less for the third seeding date than for the second seeding date at least once at each location. At Pullman in 1998, Hessian fly (*Mayetiola destructor*) (Pedigo 1989) infected 72% of spring wheat tillers on the latest seeding date, which severely reduced yield. Spring wheat 1,000-kernel weight was less for the last two seeding dates at all locations in both years (data not shown). Limited moisture (Table 2) and higher temperatures during kernel development may have contributed to the reduced kernel weight. The highest potential for dockage due to jointed goatgrass was at Lind, the driest and lowest-yielding location, for the two earliest seeding dates (data not shown). On the first seeding date in 1998 at Pullman and in 1999 at Lind, dockage was 7.3 and 5.5%, respectively, and would have resulted in substantial economic loss.

Although jointed goatgrass is a winter annual, this study demonstrates that it can germinate and establish in a spring crop and produce spikelets with viable seed before spring wheat maturity. An additional study has shown that jointed goatgrass probably is not a strict winter annual based on vernalization requirements (Walenta et al. 2002). Based on crop yield, spring-germinating jointed goatgrass plants do not compete well with spring wheat. Spring-germinating jointed goatgrass in spring wheat produced fewer spikelets than did fall-germinating jointed goatgrass, which can produce from 4,300 to 7,400 spikelets m^{-2} in winter wheat (J. P. Yenish and F. L. Young, unpublished data). Spring wheat grain quality may be affected by dockage on the earliest seeding dates and by reduced kernel weight due to environmental conditions on later seeding dates. Delayed seeding dates of spring wheat have a greater detrimental effect on crop yield potential than does competition from spring-germinating jointed goatgrass.

The primary purposes of a spring crop in a jointed goatgrass management system are to prevent viable weed seed production and facilitate depletion of weed seed in the soil seed bank. On the basis of this study, it would be advisable for growers to plant spring wheat later than the recommended seeding date in the Pacific Northwest. Spring wheat

Table 7. Effect of seeding date on spring wheat (*Triticum aestivum* L.) grain yield at Lind, WA, Pendleton, OR, and Pullman, WA, in 1998 and 1999[a]. Seeding dates are shown in Table 1.

	Spring wheat grain yield											
	Hand-sown infestation						Natural infestation					
	Lind		Pendleton		Pullman		Lind		Pendleton		Pullman	
Seed-ing date	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
	$kg\ ha^{-1}$											
1	3,215	1,855	2,770	2,770	2,600	7,735	2,980	2,010*[a]	3,255	1,445*[b]	1,835	6,570
2	3,305	1,535	2,790	2,515	2,965	7,420	2,525	1,490	2,900	2,005	1,600	6,220
3	3,095	1,080*	1,780*	2,145	1,945*	6,310	2,185	1,380	2,325	2,150	1,885	5,660
4	1,550*	1,200	1,065*	1,515*	265*[b]	5,710	825*	1,155	1,255*	1,655	180*[c]	5,080*

[a] An asterisk (*) denotes the means within a column that differ from that for the second seeding date as determined by the Dunnett method ($P < 0.05$).

[b] Spring wheat emergence affected by crusted soil surface due to rainfall.

[c] Hessian fly infestation (72% of tillers).

yields were generally not decreased at this time (Table 7), and jointed goatgrass viable seed production was either greatly reduced or eliminated (Table 5 and 6). However, growers, researchers, and crop consultants should consider the following limitations when selecting spring crops and seeding dates. Spring cereal grown for certified seed should not be grown in fields contaminated with jointed goatgrass because the harvested seed grain might contain jointed goatgrass spikelets. Seed produced on fields contaminated with jointed goatgrass cannot be certified by state crop improvement associations in Washington and Oregon. Planting certified seed that is free of jointed goatgrass should be a standard practice. Delaying the spring crop seeding date may prevent production of jointed goatgrass spikelets containing viable seed; however, some reduction in crop yield is possible. This information should be included in an integrated approach for jointed goatgrass management to reduce the potential contribution of viable jointed goatgrass seed to the soil seed bank during a spring crop cycle.

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