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Seed Survival, Germination Ability, and Emergence of Jointed Goatgrass (*Aegilops cylindrica*)[1]

WILLIAM W. DONALD[2]

Abstract. **Seed survival of jointed goatgrass over 2 yr was related to cyclical seasonal changes in ability to germinate, field emergence, and seasonal precipitation and air temperature. The ability of seed to germinate was studied by incubating spikelets under constant, defined incubation conditions after retrieving samples from the field every 2 weeks over 2 yr. Less than 8% of jointed goatgrass seed that were initially set outdoors survived beyond 2 yr when left undisturbed on the soil surface or buried 5 cm deep. Periods of greatest seed loss coincided with periods of peak emergence in fall (late September and October). The ability of seed to germinate also peaked in fall and preceded the period of greatest field emergence and greatest decreases in seed survival. Nomenclature: Jointed goatgrass, *Aegilops cylindrica* Host. #[3] AEGCY.**

Additional index words. **Dormancy, phenology, winter wheat, *Triticum aestivum*, AEGCY.**

INTRODUCTION

Jointed goatgrass, a winter annual grass weed (5, 11, 12), is a growing concern to winter wheat (*Triticum aestivum* L.) farmers in the Central Great Plains and Pacific Northwest of the United States (7). It is well adapted to reduced-tillage cropping systems, particularly in regions where climate limits cropping options to continuous wheat or the winter wheat-fallow rotation. The biology and control of jointed goatgrass were reviewed recently (7).

Field emergence of jointed goatgrass in relation to seasonal changes in seed survival and germination ability has received little research attention. Freshly sampled seed in spikelets from five Oregon selections were dormant (10). However, 1 month after collection, seed in spikelets germinated between 52 and 75% (9).

Jointed goatgrass seed remained viable after 2 yr of dry storage at laboratory temperatures (14). Survival of undisturbed jointed goatgrass seed in spikelets buried 5, 15, or 30 cm deep at five locations in Colorado, Kansas, and Nebraska decreased rapidly over the first 3 yr after burial (8). Some seed survived 3 to 5 yr in the field depending upon burial depth and site. By the third year, less than 8% of the initial number of seed buried 5 cm deep survived in the soil at all locations. At this depth no seed survived after 3, 4, or 5 yr at one, two, and four burial sites, respectively. Seed source did not contribute as much to differences in seed survival as did burial site, despite differences in initial percent germination due to seed source. Buried seed became progressively more germinable over several years so that the few seed that survived after 3 yr were all nondormant. A second seed survival study of jointed goatgrass in Idaho and Washington (14) verified many observations of an earlier study in the Central Great Plains (8). In both studies, seed survival was not influenced greatly by burial depth to 30 cm but differed between burial sites. The survival of seed in spikelets on the soil surface has not been reported.

The objective of this experiment was to determine how burial depth (surface and 5 cm deep) and time of year (samples collected every 2 weeks for 2 yr) influenced short-term seasonal changes in percent emergence, germination ability, and seed survival of jointed goatgrass seed set outdoors in spikelets.

MATERIALS AND METHODS

Seed source for field experiment. Nondormant jointed goatgrass seed were germinated and vernalized in a dark coldroom at 3 ± 2 C for 67 days in trial 1 (January 31 to April 7, 1983) and for 75 days in trial 2 (December 31, 1983, to March 14, 1984) prior to transplanting into soil on April 7, 1983, in trial 1 and on March 15 to 16, 1984, in trial 2. Transplanted seedlings were thinned to one plant per pot (10-cm diam by 95 cm; 0.5 L of soil) after establishment in the greenhouse. The Fargo silty clay soil used was a fine montmorillonitic, frigid Vertic Haplaquolls with 3% sand, 48% silt, 49% clay, 3.0% organic matter, and a pH of 8.2. Sunlight was supplemented with fluorescent lighting to provide at least a 14-h photoperiod required to induce flowering of vernalized jointed goatgrass (4, 6, 18). Light irradiance and photosynthetically active radiation of fluorescent lighting at plant height, 40 to 75 cm below fluorescent bulbs, ranged between 20 and 68 W m^{-2} and between 90 and 168 $\mu E\ m^{-2}\ sec^{-1}$, respectively. Day and night temperatures averaged 25 and 20 C, respectively, but were no greater than 28 C and no less than 18 C, respectively. Fully mature, air-dried spikelets were collected from potted greenhouse-grown plants between July 1 and August 1 in both trials and were refrigerated dry in darkness at –23 C until they were packeted and placed outdoors, less than 1.5 months later.

Field burial experiment. The treatments were burial depth (0 or 5 cm) and sampling time after seed burial (every 2 weeks over 2 yr). Fifty spikelets of jointed goatgrass were placed in each of 208 fiberglass mesh packets (5 by 7.5 cm)

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[2]Res. Agron., Cropping Systems and Water Quality Unit, Agric. Res. Serv., U.S. Dep. Agric., and Adjunct Asst. Prof., 244 Agric. Eng. Dep., Univ. Missouri, Columbia, MO 65211.

[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Table 1. The frequency distribution of jointed goatgrass spikelets with one, two, or three seed in spikelet samples used in trials 1 and 2[a].

Trial	Seed per 100 spikelets	Proportion with seed per spikelet 0	1	2	3
	no.	%			
1	99 ± 1	14 ± 3	41 ± 3	44 ± 4	1 ± 1
2	101 ± 3	4 ± 1	30 ± 4	66 ± 4	0
LSD (P = 0.05)		8	NS	13	. . .

[a]Means and standard errors are presented.

made of 14-mesh nylon window screen (5.5 wires per linear cm) which were either secured to the soil surface with 10-cm-long tent stakes or were buried 5 cm deep in pots of soil (described above). Seed number per spikelet is summarized for both trials in Table 1. The site was not tilled over the course of the experiment. Weeds in pots were controlled by periodic hand pulling, whereas weeds between pots were controlled by hoeing and hand pulling. Precipitation (Figure 1) and air temperature (Figure 2) were obtained from an official weather station approximately 0.5 km north of the experimental site at Hector Airport, Fargo, ND (Figure 1). The experiment was arranged in the field as a randomized complete block design with four blocks and was repeated in time (trials 1 and 2). Four seed packets per depth were sampled from each block every 2 weeks for 2 yr. Spikelet persistence was defined as the number of intact spikelets recovered at each sampling time from the field as a percent of the number of spikelets (N = 50) initially placed outdoors. Spikelets were washed free of soil with tapwater before being placed in germination paper subirrigated with deionized water.

The number of seed that germinated from intact spikelets was determined after incubation in darkness at 20 C (15) and 100% relative humidity for 3 weeks. Brief exposure to laboratory light did not influence germination of dormant jointed goatgrass seed. After 3 weeks, the remaining ungerminated seed were removed from spikelets and germinated in subirrigated germination paper under the same incubation conditions for an additional 3 weeks. Then the number of additional seed that germinated 3 weeks after spikelet removal and ungerminated (dormant plus dead) seed were counted. Percent germination was calculated from the sum of germinated seed after 3 and 6 weeks, expressed as a percent of the number of seed set outdoors at the start. The number of seed initially set outdoors was estimated as the mean number of seed per 50 spikelets (N = 4) (Table 1). The tetrazolium test was unreliable for distinguishing the number of dead and dormant seed of jointed goatgrass remaining after 6 weeks. Surviving seed are defined as the sum of the total number of germinated seed after 3 and 6 weeks plus the number of intact, sound, unmoldy seed remaining 3 weeks after spikelet removal.

Emerged jointed goatgrass seedlings were counted at 7-day intervals during periods of maximum field emergence in fall and at longer intervals during other seasons. Emergence was followed for the same four packets either placed on the soil surface or buried 5 cm deep. The term "emergence" is used to describe establishment of seedlings from surface seed even though seedlings did not emerge through the soil surface. Established seedlings were removed after observation and percent emergence was calculated as the number of emerged seedlings as a percent of the number of seed initially present in 50 spikelets (Table 1).

Percent seed survival was subjected to linear regression over time after natural log (ln) transformation of (% seed surviving + 1) using SPSS-PC+ software[4] (13, 16, 19). Seed survival was assumed to be described by the equation $N = N_o \exp^{(-k)(t)}$, where N = percent seed survival, N_o = 100 at time = 0 days, t = time after the start in days, and –k is a constant. The linear form of this equation, $[\ln(N + 1) = \ln(100 + 1) - (k)(t)]$, was subjected to linear regression to calculate –k.

RESULTS AND DISCUSSION

Seed per spikelet. Jointed goatgrass seed is dispersed in spikelets which disarticulate from the spike (7). Because only spikelets are dispersed and the spikelet may influence the phenology of seed survival, germination, and field emergence over time, it was appropriate to study short-term (2-yr) seed survival using spikelets rather than seed removed from spikelets. Using the average number of seed per 50 spikelets initially placed outdoors (Table 1) as a basis to calculate percent seed survival, germination, and emergence over time introduced some error into these estimates. Because individual spikelets contained zero to three seed, total seed number

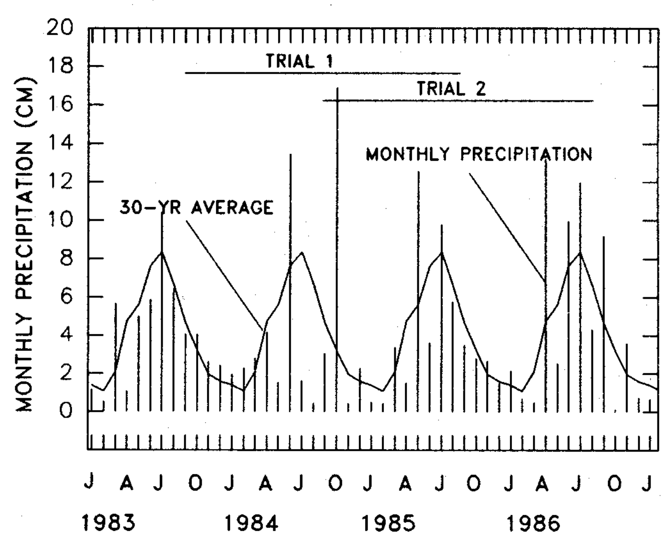

Figure 1. Monthly precipitation (vertical bars) and the 30-yr average precipitation (curve) over the course of trials 1 and 2.

[4]SPSS, Inc., 444 N. Michigan Ave., Chicago, IL 60611.

per 50 spikelets varied somewhat from packet to packet even though each packet contained 50 spikelets at the start of each trial. Total seed number per 100 spikelets also was less in this experiment (mean ± standard error = 99 ± 1 and 101 ± 3 seed per 100 spikelets in trials 1 and 2, respectively) than in a previous seed survival experiment (190 ± 2 and 183 ± 2 seed per 100 spikelets) (8). Spikelets used for this experiment were gathered from greenhouse-grown plants, whereas spikelets from field-grown plants were used in the previous experiment (8), perhaps explaining the difference in seed number per 100 spikelets.

Percent emergence. Surface seed were expected to germinate and emerge earlier and over a shorter period than buried seed, as observed for other species when soil moisture is sufficient for germination (2). Emergence of jointed goatgrass from surface seed was limited, but greater than from buried seed, during the first fall in trial 1 when fall rainfall was limited (Figures 1 and 3 to 6), but was similar for both surface and buried seed during the first fall of trial 2 when fall rainfall was above normal.

Emergence lasted about 4 weeks in the fall (late September and October) in both trials for both surface and buried seed, as observed in other winter annuals (2, 17). Although jointed goatgrass emerged over a similar period in both years in both trials, total percent emergence differed quantitatively between years (Figures 3 to 6). In trial 1, 5 ± 1% (mean ± standard deviation) of surface seed emerged during the first fall, whereas 53 ± 6% were germinable. In contrast, 26 ± 1% and 29 ± 8% of surface seed emerged and were germinable, respectively, in trial 2.

Quantitative differences in percent emergence and emergence phenology of jointed goatgrass between surface and buried seed (Figures 3 to 6) may be related to year-to-year differences in fall rainfall (Figure 1). Limited fall precipitation during the first fall probably prevented germination and limited emergence of jointed goatgrass for 1 yr in trial 1 until the subsequent fall when precipitation was sufficient for germination and emergence, even though seed were able to germinate when sampled biweekly and incubated under constant conditions during the first fall. In trial 2, emergence peaked during the first fall following October rainfall. However, emergence was more limited during the second fall

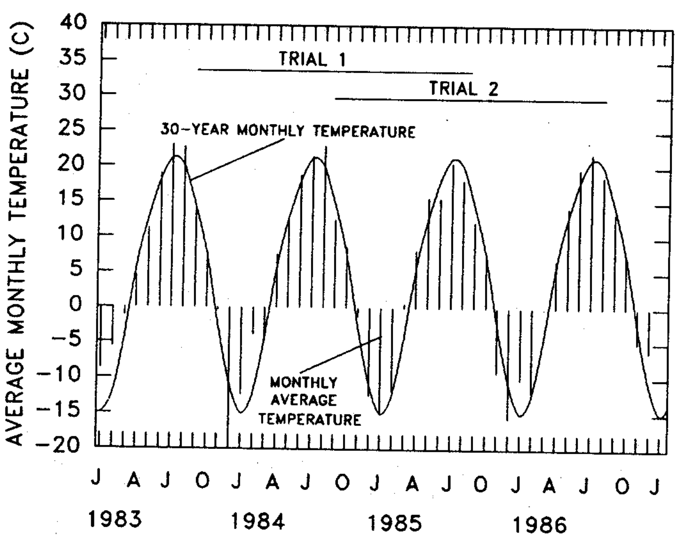

Figure 2. Monthly average air temperature (C) (vertical bars) and the 30-yr average temperature (curve) over the course of trials 1 and 2.

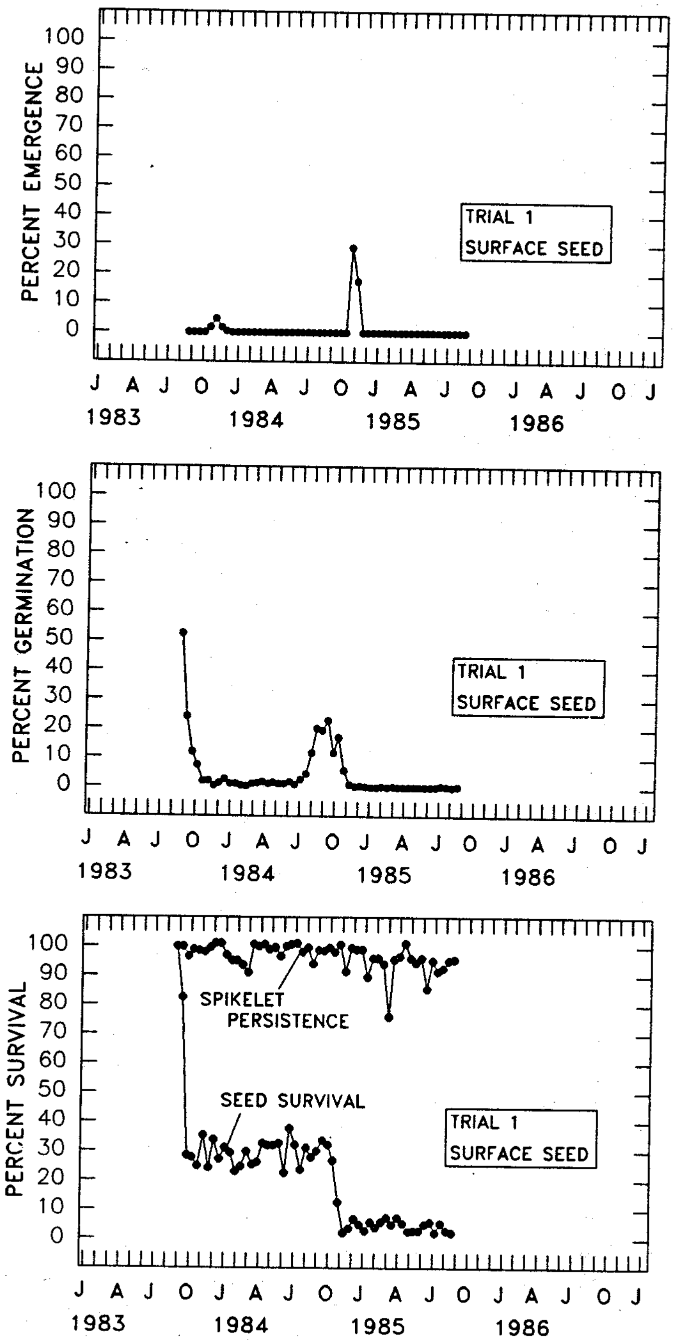

Figure 3. Percent emergence, germination ability, spikelet persistence, and seed survival for surface seed in trial 1.

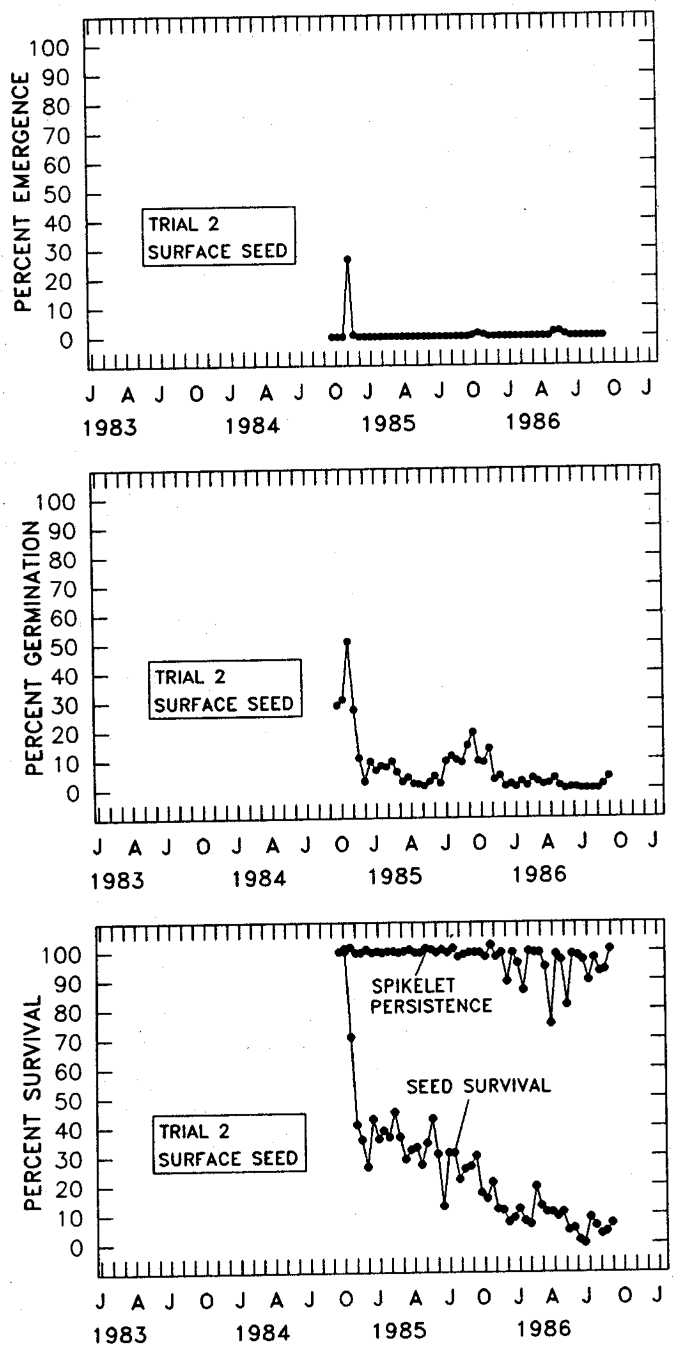

Figure 4. Percent emergence, germination ability, spikelet persistence, and seed surviving for surface seed in trial 2.

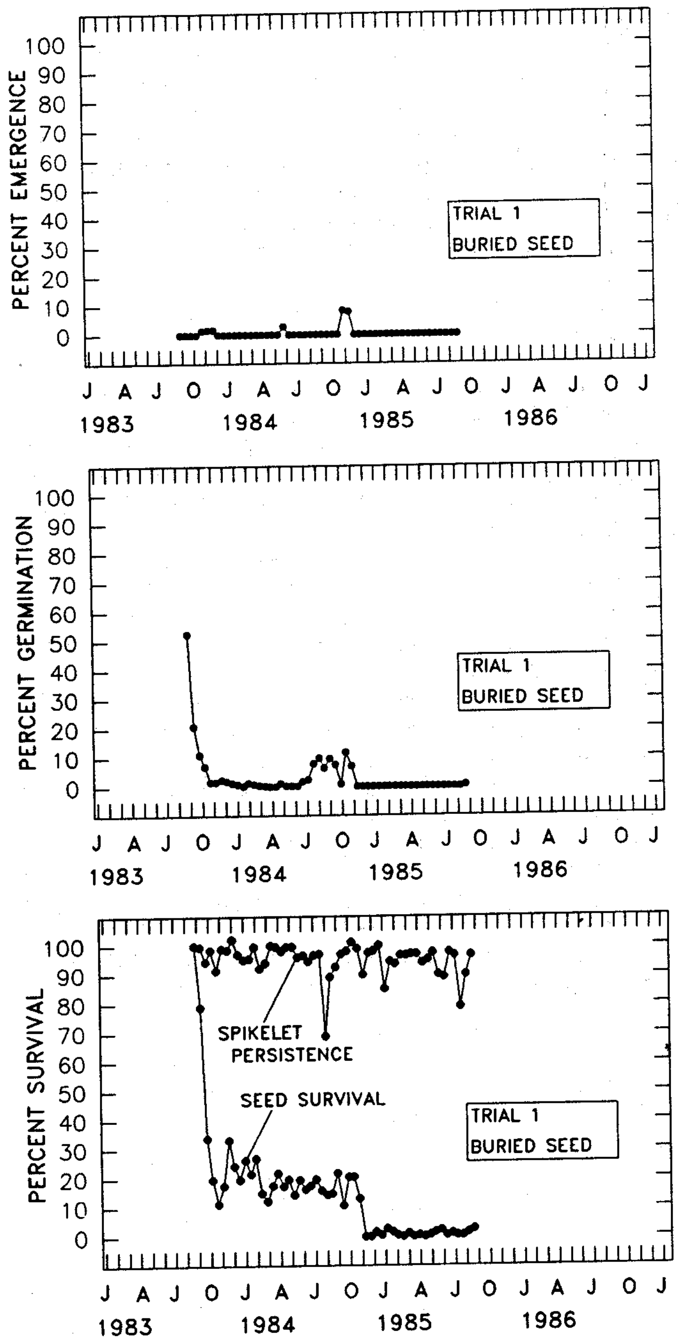

Figure 5. Percent emergence, germination ability, spikelet persistence, and seed survival for seed buried 5 cm deep in trial 1.

in trial 2 compared to the second year of trial 1, presumably because fewer seed survived into the second year of trial 2 than into the second year of trial 1. Adequate soil moisture often plays a secondary permissive role to temperature in regulating emergence timing and duration of other winter annuals (3, 14). Emergence phenology can be altered in response to different year-to-year patterns of fall rainfall (3). Lack of rainfall delayed germination and emergence of some winter annuals as much as 1 month in fall (3), much less than observed in this experiment.

Percent germination. Seed were partially dormant when first set outdoors, as observed before (9). The ability of seed to germinate peaked during the first fall (late September and

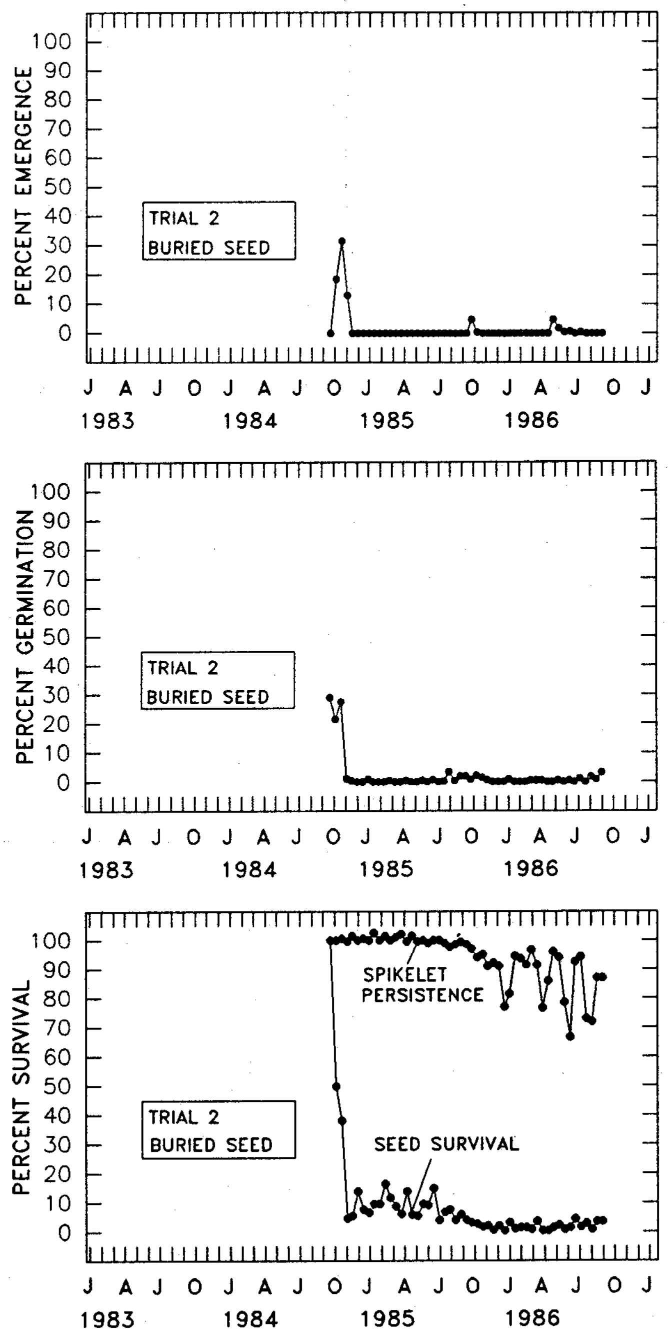

Figure 6. Percent emergence, germination ability, spikelet persistence, and seed survival for seed buried 5 cm deep in trial 2.

October) for both surface and buried seed (Figures 3 to 6). Surface seed were better able to germinate under constant, favorable incubation conditions than buried seed.

Seed were able to germinate over a longer period than they were able to emerge in the field (Figures 3 to 6). In both trials, the period of peak emergence during the first fall lagged 4 weeks after germinability initially increased for both surface and buried seed, respectively. During the second fall peak emergence lagged 4 and 6 weeks behind initial increases in germinability for surface and buried seed, respectively, in trial 1.

Under constant conditions, jointed goatgrass seed were able to germinate in fall before becoming dormant during winter (December) (Figures 3 to 6). Low winter temperatures (Figure 2) likely imposed secondary dormancy so that seed could not germinate and emerge in spring, as observed in other winter annuals (2). Jointed goatgrass seed probably required high summer temperatures for afterripening, but high summer temperature and lack of adequate moisture probably limited germination during summer (15). The regulatory role of seasonal temperature cycles on seed dormancy cycles of winter annuals has been reviewed (1, 2, 3) but has not been reported for jointed goatgrass.

Percent seed survival. In trial 1, periods of greatest seed loss during the first and second falls coincided with periods of peak field emergence, but fewer seedlings emerged than expected based on decreases in percent seed survival. Presumably, unemerged germinated seed died over winter due to either microbial decay, depletion of seed storage reserves, winterkill, or seed predation. Coincidence between periods of peak seed loss and peak emergence was not as obvious in trial 2 as in trial 1, presumably due to differences between trials in which sufficient soil moisture was available for germination.

Less than 8% of jointed goatgrass seed survived after 2 yr for both surface or buried seed whether precipitation (Figure 1) was limited during the first fall, as in trial 1, or was adequate for appreciable field emergence during the first fall, as in trial 2 (Figures 3 to 6). In an earlier jointed goatgrass seed survival study (8), most seed buried 5 cm deep also did not survive beyond 3 yr. By the end of the second year of each trial, more surface seed than buried seed survived. Between 504 and 730 days after burial, the percent of surviving surface and buried seed averaged 4.4 ± 0.6% (mean ± standard error) and 0.8 ± 0.2%, respectively, in trial 1 ($P \geq F = 0.05$ for t-test) and 7.3 ± 0.7 and 1.9 ± 0.3%, respectively, in trial 2 ($P \geq F = 0.05$ for t-test).

Seed likely would survive longer when left undisturbed in this study than in tilled fields because seed survival rate is reduced by tillage (16). Consequently, results (Figures 3 to 6) likely overestimate seed survival in winter wheat production systems using tillage. This experiment verifies previous research (8) showing that jointed goatgrass seed exhibited "Type III" seed bank characteristics (20). Type III seed banks have a large nonpersistent component from which many seed germinate soon after release, but a small proportion of the seed population may survive for several years.

Reportedly, percent seed survival of jointed goatgrass is best modeled as a negative exponential function of time after burial (14, 16). In Idaho and Washington, percent seed viability data (not seed survival) were fitted to a log-linear model over time and the predicted time to loss of 99% viability was 2.8 and 5.4 yr, respectively (14). Adjusted coefficients of determination (adj. R^2) for log-linear regres-

Table 2. Linear regression equations of seed survival[a] over time[b] at two depths.

Trial	Depth	Regression equation[c]	P>F	Adj. R^2
	cm			
1	0	$\ln(\hat{Y} + 1) = \ln(101) - 0.0044\ (\pm 0.0003) \cdot (X + 1)$ ***	0.0001	0.57
	5	$\ln(\hat{Y} + 1) = \ln(101) - 0.0056\ (\pm 0.0003) \cdot (X + 1)$ ***	0.0001	0.69
2	0	$\ln(\hat{Y} + 1) = \ln(101) - 0.0041\ (\pm 0.0002) \cdot (X + 1)$ ***	0.0001	0.64
	5	$\ln(\hat{Y} + 1) = \ln(101) - 0.0037\ (\pm 0.0003) \cdot (X + 1)$ ***	0.0001	0.48

[a]Seed survival = Y as a percent of the initial number of seed set outdoors.

[b]Time = X in days over a 714-day period starting in fall in both trials.

[c]Equations were constrained to pass through ln(101). Slopes are expressed as means and standard errors. All slopes were significantly different (***) from 0 at P = 0.0001.

Table 3. Spikelet persistence[a] over time[b] at two depths.

Trial	Depth	Regression equation[c]	P>F	R^2
	cm			
1	0	$\hat{Y} = 99.8\ (\pm 0.9)$*** $- 0.0087\ (\pm 0.0022) \cdot X$***	0.0001	0.07
	5	$\hat{Y} = 97.9\ (\pm 1.3)$*** $- 0.0073\ (\pm 0.0032) \cdot X$*	0.0224	0.03
2	0	$\hat{Y} = 101.6\ (\pm 1.1)$*** $- 0.0111\ (\pm 0.0027) \cdot X$***	0.0001	0.08
	5	$\hat{Y} = 104.9\ (\pm 1.6)$*** $- 0.0311\ (\pm 0.0040) \cdot X$***	0.0001	0.23

[a]Spikelet persistence = Y as a percent of the initial number of spikelets set outdoors.

[b]Time = X in days over 730 days starting in fall in both trials.

[c]Intercepts and slopes are expressed as means and standard errors and were significantly different from 0 (* represents P = 0.05 and *** represents P = 0.001).

sion equations of seed survival over time (Table 2) showed that such models described only 48 to 69% of data variability of the present experiment. When reexpressed as negative exponential equations using –k values derived as described in MATERIALS and METHODS, such log-linear models underestimated rapid decreases in percent seed survival during the first half year after burial at both depths and overestimated percent seed survival of surface seed thereafter.

Spikelet persistence. Spikelets persisted largely intact over 2 yr whether or not they were buried (Figures 3 to 6). Buried spikelets turned brown more rapidly than did surface spikelets over the first winter and darkened thereafter, probably due to microbial degradation. Spikelets gradually decomposed as a linear function of time. Linear regression equations described spikelet persistence (= Y) over time (= X) better than did higher other polynomial functions, but coefficients of determination (R^2) were low for linear equations, due to data variability (Table 3).

Data from this experiment (Fig. 3 to 6) and an earlier experiment on jointed goatgrass quantitative vernalization requirement for flowering (6) establish that jointed goatgrass behaves as a "strict winter annual" (2). Criteria for strict winter annuals include: a) seed germinate only in fall, b) seed are dormant during summer when seedlings are unlikely to survive high temperatures, c) seed have secondary innate dormancy after summer afterripening, and d) seedlings and established plants tolerate overwinter temperatures and have a winter annual growth habit (3). In North Dakota, jointed goatgrass planted outdoors after May failed to flower during the same summer (6), indicating that cold was needed for flowering, a requirement that is typical of winter annuals having a quantitative requirement for cold to flower (6).

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