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ABSTRACT

Seed dormancy and slow seedling development often limit establishment of warm-season grass stands. Establishment of seedlings with two solid matrix seed priming (SMP) treatments [2-d moistened (17°C) and 14-d wet-chill (4°C)] was compared with untreated seed of 'Kaw' and 'Pawnee' big bluestem (*Andropogon gerardii* Vitman) and 'Pathfinder' and 'Cave-in-Rock' switchgrass (*Panicum virgatum* L.) in greehouse and field experiments. In two greenhouse studies, seedling emergence was monitored from 7 to 26 d after planting and number of adventitious roots were monitored from 2 to 5 wk after planting. Field experiments were initiated on 19 Apr. 1988, 3 June 1988, and 23 May 1989, on a Sharpsburg silty clay loam (fine montmorillonitic, mesic, Typic Argiudolls). In the greenhouse, SMP treatments increased big bluestem emergency by 18%. In the field, final seedling emergency from dry untreated big bluestem seed was equal to or higher than that of SMP-treated seed. The SMP treatments had no effect on adventitious root formation for big bluestem in either greenhouse or field experiments. In the greenhouse, the moistened and wet-chill treatments increased seedling emergency of switchgrass 35 and 150%, respectively. In the greenhouse, SMP treatments slightly increased the percentage of switchgrass plants with adventitious root development 5 wk after planting but not in the field studies. Number of adventitious roots per plant were unaffected by treatment. In the field, the SMP-treated seed produced the highest seedling emergence for switchgrass under moist planting conditions and had the potential to improve stands when seed was planted without drying. However, final seedling emergence from dry untreated seed was greater than that for SMP-treated seed under dry soil conditions.

RAPID ESTABLISHMENT of warm-season grasses is often limited by dormant seed, slow seedling establishment, and weed competition. A procedure to reduce dormancy and increase the speed of germination and seedling emergence would improve stand establishment.

Chilling imbibed seed for a minimum of 14 d at 4°C is considered effective in breaking switchgrass dormancy (Weisner, 1990). A 30-d 4°C chill treatment increased germination 32% over the control (Sautter, 1962). Germination of big bluestem and switchgrass seed was increased 24 and 338%, respectively, over the control by chilling at 4°C for 14 d (Hsu et al., 1985). Indiangrass [*Sorghastrum nutans* (L.) Nash] seed of various ages reached near maximum potential germination following a 28-d moist-chill treatment (Emal and Conard, 1973).

Priming is an osmotic conditioning process where seed is hydrated to a level that pregermination metabolic activity is initiated but emergence of the radicle does not occur (Bradford, 1986). A 70-h, 17.2°C priming treatment produced 56% emergence in crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schultes] compared to 1% for the untreated control 67 h after planting in a greenhouse experiment (Keller and Bleak, 1968). In field experiments with crested wheatgrass, primed seed produced proportionally better stands as soil moisture at planting decreased (Bleak and Keller, 1970). The benefit of priming was lost as planting date was delayed from the recommended date (Bleak and Keller, 1974).

Extending the priming treatment until the radicle emerged was not necessary to achieve increased kleingrass (*Panicum coloratum* L.) seedling emergence over the control (Hauser, 1981). Hauser (1986) reported that priming switchgrass seed increased germination by 46% over the control but big bluestem did not respond to priming. Field growing conditions did not alter the relative effectiveness of priming for switchgrass. Superficial drying of crested wheatgrass seeds after priming, however, reduced seedling emergence and rate of emergence (Bleak and Keller, 1969). Enhancing the rate of seedling emergence could shorten the time until adventitious roots are initiated. Grass seedlings become permanently established when adventitious roots formed at the coleoptilar node (Newman and Moser, 1988).

Solid matrix priming (SMP) is a process where seed is mixed with a particulate solid matric material and provided aeration and only enough water to allow osmoconditioning, but not germination (Eastin, 1990). After SMP of seeds under 15°C, 14-h day, and 10°C, 10-h night conditions in growth chambers, seedlings of pepper (*Capsicum annuum* L.) and tomato (*Lycopersicon esculentum* Mill.) began emerging 2 and 4 d, respectively, before seedlings from non-primed or commercially primed seed (Kubik et al., 1988). Untreated or ungerminated seeds of cucumber (*Cucumis sativus* L.), cowpea [*Vigna unguiculata* (L.) Walp.], corn (*Zea mays* L.), okra [*Abelmoschus esculentus* (L.) Moench], soybean (*Glycine max* L.), and tomato were not adversely affected when planted in a gel carrier with a fluid drill (Ghate et al., 1987).

The objective of this study was to evaluate the effects of two solid matrix seed priming methods (moistened and wet-chill) on seed germination, seedling emergence, and adventitious root development of big bluestem and switchgrass without drying the seed prior to planting.

MATERIALS AND METHODS

Kaw and Pawnee big bluestem and Cave-in-Rock and Pathfinder switchgrass were used because they are widely grown in the central USA. Seed harvested in 1987 was used in the greenhouse experiments and the 1988 field experiments, while seed harvested in 1988 was used in the 1989 field experiment. Viability tests were conducted by the Nebraska Crop Improvement Association using standard AOSA procedures (Weisner, 1990). Total live seed (viability) was determined with a tetrazolium (2, 3, 5-triphonyl-2H-tetrazolium chloride) test (Grabe, 1970) and the dormant seed was determined by subtracting the actual germination percent from the percent total live seed. Kaw and Pawnee big bluestem had 69 and 81% germination, respectively, for the 1987 seed and 77 and 90%, respectively, for the 1988 seed with no dormancy either year. Pathfinder

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Abbreviations: PLS, pure live seed; and SMP, solid matrix seed priming.

and Cave-in-Rock switchgrass had 86% germination and 7% dormant seed, and 39% germination and 56% dormant seed, respectively, for the 1987 seed. For the 1988 seed, Pathfinder had 80% germination and 13% dormancy and the Cave-in-Rock had 25% germination and 72% dormancy. To facilitate planting of the big bluestem seed, the pubescence was mechanically removed from the seed prior to seed treatment.

Seed treatments to test the affects of a SMP method (Eastin, 1990) on seedling emergence and establishment included two priming treatments, 2-d of wetting without chilling (2-d moistened, 17°C) and a 14-d of wetting with chilling (14-d wet-chill, 4°C). The moistened treatment was accomplished by mixing seed, SMP medium and Captan {*n*-[(trichloromethyl)-thio]-4-cyclohexene-1, 2-dicarboximide} fungicide solution (21 g kg^{-1}) in the ratio of 100 g seed, 100 g SMP medium, and 50 mL fungicide solution, and then holding the mixture for 2 d at 17°C in a loosely tied plastic bag. The bags were gently shaken at 24 h. The 14-d wet-chill treatment consisted of seed from the same lots, SMP medium, and fungicide mixture, held at 4°C for 14 d in a loosely-tied bag. The bags were gently shaken and observed for fungal growth every 2 d. The SMP medium had a matrix potential of -6 MPa at the ratio of seed, SMP medium, and fungicide solution used. After SMP-treatment, the seeds were either planted directly (greenhouse experiments) or suspended in a 20 kg g^{-1} N-Gel TM[1] (Aqualon Co., Wilmington, DE) and seeded immediately with a fluid drill (field experiments). The fluid drill seeded two rows and metered the gel-seed mixture into the furrow opened by a disk which provided shallow coverage. These techniques preserved any wet-chill or other priming effects.

Untreated seed stored at room temperature was used as a control in both greenhouse and field experiments. In field experiments the fluid-drill control consisted of dry seed, SMP medium, and tap water mixed in the 2:2:1 ratio just prior to planting. The fluid-drill control determined if the gel seeding method influenced emergency of untreated seed. Addition of water to the fluid-drill control was required to keep the dry SMP medium from absorbing the water from the gel solution and thus not allowing the slurry to pass through the drill. The initiation of treatments was sequenced so that planting date was consistent for all treatments.

Greenhouse Experiments

Two greenhouse experiments were conducted. Switchgrass and big bluestem seeds were hand-planted at 85 and 145 pure live seeds (PLS) m^{-1} of row, respectively, to a depth of about 0.5 cm into 34- by 50- by 9-cm flats containing 2:1:1 mixture of Sharpsburg silty clay loam soil, peat moss, and sand. Seed viability was determined by a tetraozolium test. Captan (*N*-trichloromethylmercapto-4-cyclohexene-1,2-diacarboximide) fungicide solution (21 g kg^{-1}) was used in the first watering immediately after planting. Flats were top-watered as needed to keep the soil moist. Temperature was maintained at 24 ± 2°C. Emergence was recorded 7, 10, 14, 16, 21, and 26 d after planting. Percent emergence was calculated by dividing the number of emerged plants by the number of PLS planted. For each species the experimental design was a randomized complete block with four replicates. Two experimental units (5 rows each) were included in each flat. The data from the two experiments were combined because the error variances were homogenous according to Bartlett's test (Steele and Torrie, 1980). Emergence data are reported as percentages because arcsin transformation was not necessary. Final emergence data were analyzed as a 2 (cultivar) by 3 (treatment) factorial for each species. Main effects and interactions were analyzed by single-degree-of-freedom contrasts where appropriate.

Switchgrass and big bluestem seedlings grown in the greenhouse were excavated at 2, 3, 4, and 5 wk after planting. A random row (experimental unit) was harvested in each greenhouse flat and all of the adventitious roots on all of the seedlings were counted and averaged. The number of seedlings ranged from 15 to 35 and 5 to 20 for big bluestem and switchgrass, respectively. Average number of adventitious roots (roots at coleoptilar node) on plants with adventitious roots and percentage of plants with adventitious roots were determined. Since error variances were homogeneous, data from the two trials were combined and analyzed by species. The final root development data were analyzed as a 2 by 3 factorial experiment. Single-degree-of-freedom contrasts were used to test main effects and interactions where appropriate.

Field Experiments

Field experiments were conducted in 1988 and 1989 on Sharpsburg silty clay loam at the University of Nebraska Research and Development Center, near Mead. Average annual precipitation is 700 mm with about 500 mm occurring during the growing season (1 April –30 September). However, the 1988 and 1989 growing seasons were dry with only 376 and 427 mm of precipitation, respectively.

Seeding rates were 80 and 90 PLS m-1 of row for big bluestem and switchgrass, respectively. Two-row plots (0.7 by 6 m) were arranged in a randomized complete block design with four replicates. The dry control was planted with a cone seeder while the SMP treatments and the fluid-drill control were seeded with an experimental fluid drill with a proportionary fluid drilling mechanism. Planting depth was 1 cm. All fluid-drilled treatments were suspended in the gel solution and seeded immediately. Planting dates were 19 Apr. 1988, 3 June 1988, 3 May 1989, and 23 May 1989 to represent early- and late-season planting dates (each year). However, there was no seedling emergence in the 3 May 1989 seeding. Atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1, 3, 5-triazine-2, 4-diamine] was applied post-plant at the rate of 2.3 kg a.i. ha^{-1} to control weeds.

Emergence was monitored by marking two random 1-m sections of row in the plots (one in each row) and recording the number of seedlings. Emergence counts were taken 28, 35, 41, 45, and 50 d after planting for the 19 Apr. 1988 date; 20, 24, 30, and 42 d after planting for the 3 June 1988 date; and 32, 36, 42, and 52 d after planting for the 23 May 1989 date. Percent emergence was calculated as in the greenhouse experiments. Plots were irrigated (19 mm total) over the 4 d following the 23 May 1989 planting because of dry soil conditions.

Arcsin transformation of the data was not necessary. Error variances were pooled. Final emergence for each species within planting date was analyzed as a 2 by 3 factorial. Single degree of freedom contrasts were used to test main effects and inter-

Table 1. Influence of cultivar and solid matrix priming on seedling emergence† of two cultivars each of big bluestem and switchgrass 26 d after planting in the greenhouse.

Treatment	Big bluestem		Switchgrass	
	Kaw	Pawnee	Cave-in-Rock	Pathfinder
			%	
Dry control	49	31	19	21
Primed				
Moistened (2 d, 17°C)	55	43	24	30
Wet chill (14 d, 4°C)	54	36	40	60
Single degree of freedom contrasts averaged over cultivars ($P > F$)				
Control vs primed	<0.01		<0.01	
Within primed				
Moistened vs wet chill	0.13		<0.01	
SE	1.91		2.93	

† Percent emergence = $\frac{\text{Total number of seedlings emerged}}{\text{Total number of seeds planted} \times \text{percent viability (Tetrazolium test)}}$

[1]Use of trade names are for indentification purposes and does not constitute endorsement by the authors or their institutions.

Table 2. Influence of solid matrix priming on number of adventitious roots and percent of plants with adventitious roots for two cultivars each of big bluestem and switchgrass 5 wk after planting in the greenhouse.

Parameters	Big bluestem						Switchgrass					
	Kaw			Pawnee			Cave-in-Rock			Pathfinder		
	Dry control	Moistened	Wet chill	Dry control	Moistened	Wet chill	Dry control	Moistened	Wet chill	Dry control	Moistened	Wet chill
Avg. root number†	2.0	1.9	1.8	2.4	2.4	2.3	2.9	2.8	3.1	3.2	3.5	3.3
Percent of plants with adventitious roots	77	88	82	88	88	87	80	86	97	94	97	99
	P > *F*											
Ave. root number	Treatment main effect (*P* = 0.53), SE = 0.094 Cultivar main effect (*P* ≤ 0.01)						Treatment main effect (*P* = 0.78), SE = 0.190 Cultivar main effect (*P* = 0.10)					
Percent of plants with adventitious roots	Treatment main effect (*P* = 0.24), SE = 2.41 Cultivar main effect (*P* = 0.07)						Treatment main effect (*P* = 0.05), SE = 3.12 Cultivar main effect (*P* = 0.01) Single degree of freedom contrasts for treatment control vs avg of primed (*P* = 0.05) SE = 1.8 moistened vs chill (*P* = 0.14)					

†Average number of adventitious roots on plants with adventitious roots.

actions where appropriate. Data from the planting dates were not combined due to nonhomogeniety of error, as determined with Bartlett's test. A probability level of $P \leq 0.05$ was used to determine significance in all of the experiments.

RESULTS AND DISCUSSION

Big Bluestem

Greenhouse Experiments

When averaged over cultivars the SMP treatments significantly increased seedling emergence over that of the control (Table 1). Average seedling emergence over the three treatments was 43% greater for Kaw than for Pawnee. The cultivar-by-treatment interaction was nonsignificant. The two primed treatments did not differ significantly. The decrease in final seedling emergence of Pawnee for the wet-chill treatment may have been caused by a fungal growth that developed during the second trial. Rate of emergence did not vary among treatments between cultivars (data not presented).

At 5 wk after planting, Pawnee had significantly more adventitious roots per plant and a slightly higher percentage ($P = 0.07$) of plants with adventitious roots than Kaw (Table 2). The SMP treatments did not affect the average number of adventitious roots per plant or the percentage of plants with adventitious roots for either cultivar.

Table 3. Influence of solid matrix priming on seedling emergence† of big bluestem and switchgrass sampled 50 d (19 April 1988), 42 d (3 June 1988), and 52 d (23 May 1989), after planting.

	Big bluestem			Switchgrass		
	Planting date					
Treatment‡	19 April 1988	3 June 1988	23 May 1989	19 April 1988	3 June 1988	23 May 1989
	%					
Dry control	40	12	15	13	5	10
Fluid-drill control	25	4	16	18	1	5
Primed						
Moistened (2 d, 17°C)	43	11	11	21	2	5
Wet-chill (14 d, 4°C)	27	11	14	22	10	6
Single degree of freedom contrasts (P > F)						
Dry control vs. all others	<0.01	0.03	0.69	<0.01	0.03	<0.01
Fld control vs avg of prime	<0.01	<0.01	0.18	0.08	<0.01	0.62
Within primed Moistened vs wet-chill	<0.01	0.87	0.37	0.59	<0.01	0.49
SE	2.55	1.47	2.31	1.58	0.39	0.92

† Percent emergence = see Table 1.
‡ Values were averaged over cultivars within each species.

Field Experiments

Cultivars did not differ significantly for seedling emergence. In addition, the cultivar-by-treatment interactions were not significant for any planting date. Therefore, the data for the two cultivars were combined for analysis.

Seedling emergence varied among planting dates and among treatments within a planting date (Table 3). Seedling emergence for the dry control was significantly greater or similar to that for all other treatments. In comparison to the primed treatments, the fluid-drill control gave significantly lower seedling emergence on two of the three planting dates. Seedling emergence for the fluid-drill control treatment was less than that for the dry control on two of three planting dates. Rapid imbibition by the dry seeds after placement in the gel before planting may have caused irreversible tissue damage. The moistened treatment gave significantly greater seedling emergence than the wet-chill treatment on only one of the three planting dates. There was no difference between the primed treatments for the other two planting dates. Seed treatments did not differ significantly for seedling emergence for the single planting date in 1989. Rate of seedling emergence, however, was greatest for the fluid-drill control treatment (data not presented). As in the greenhouse study, adventitious root development was not influenced by seed treatment (data not presented).

Differences among planting dates for seedling emergence can be attributed primarily to soil moisture at time of planting and to subsequent precipitation. The 19 Apr. 1988 planting received adequate precipitation for seed germination, seedling emergence, and seedling growth. The reduction in seedling emergence for the wet-chill treatment, like that in the greenhouse, may have been the result of fungal growth.

Although soil moisture was adequate for the 3 June

1988 planting, 7 d of high temperatures (up to 38°C), reduced and delayed seed germination and seedling emergence. The 23 May 1989 planting was made into dry soil. Seed germination and seedling emergence did not occur until 4 wk later when significant precipitation was received. There appeared to be no advantage for the SMP treatments for big bluestem. Even with the dry conditions following the 23 May 1989 planting, all treatments achieved a successful stand equivalent to 11 plants m^{-2} (Launchbaugh and Owensby, 1970) except for the fluid-drill control treatment in the 3 June planting.

Switchgrass

Greenhouse Experiments

The SMP treatments signficantly increased seedling emergence compared to the control (Table 1). The cultivar-by-treatment interaction was nonsignificant. Average seedling emergence was greater for Pathfinder than that for Cave-in-Rock. Seedling emergence averaged over cultivars from the wet-chill treatment was 150 and 85% greater than that for the dry control and the moistened treatments, respectively.

There were no significant cultivar or treatment effects on adventitious root numbers 5 wk after planting (Table 2). The percentage of plants with adventitious roots was significantly greater for the primed treatments than that for the control. Pathfinder had significantly more plants with adventitious roots than Cave-in-Rock.

Field Experiments

Pathfinder had significantly higher final seedling emergence than Cave-in-Rock for all planting dates (data not presented). Treatment-by-cultivar interactions were not significant for any planting date for final emergence so cultivars were combined for analysis.

Effects of treatments on seedling emergence varied among planting dates (Table 3). Final seedling emergence for the 19 April seeding was significantly higher for the SMP-treated seed than that for the dry control ($P \leq 0.01$), however, only slightly greater than that for the fluid-drill control ($P = 0.08$). Moisture conditions were adequate for seedling emergence and growth for the 19 April seeding, so excellent stands were obtained for all treatments. The SMP-treated seeds produced a more rapid rate of seedling emergence which enabled them to take advantage of good growing conditions. For the 3 June study the wet-chill treatment gave the greatest seedling emergence. Very little seedling emergence occurred with the fluid-drill control and the moistened seed treatments. Although soil moisture was not limiting at seeding for the 3 June planting, extremely high day-time temperatures (7 d up to 38°C daily maximum) followed planting. The seedlings from the wet-chill treatment emerged within 2 d of planting and lived through the hot conditions without rainfall. Seedlings from the dry, untreated control did not emerge until after the hot, dry weather ceased. Only the dry-control and the wet-chill treatments produced successful stands equivalent to at least 11 plants m^{-2} (Launchbaugh and Owensby, 1970).

Seedling emergence for the dry control was greater than that for any of the seed treatments for the extremely dry conditions with the 23 May 1989 seeding. There were no significant differences in seedling emergence among any of the other seed treatments. All treatments produced successful stands equivalent to at least 11 plants m^{-2} in 1989 (Launchbaugh and Owensby, 1970).

Adventitious root development on seedlings was not affected by seed treatment in any of the field experiments (data not presented). Timing of precipitation may limit any potential increased rate of root development (Newman and Moser, 1988) caused by SMP treatments.

Under greenhouse conditions the wet-chill seed treatment greatly increased switchgrass seedling emergence regardless of dormancy level. However, under field conditions the effects of seed priming were often masked because of environmental conditions. Solid-matrix-primed seed is generally dried to a level to permit storage before planting (J. A. Eastin, 1991 personal communication). Primed seeds of these species need to be evaluated after being redried to determine (i) if the positive effect of a wet-chill treatment on switchgrass can be maintained with redrying, and (ii) if seeds of both switchgrass and bluestem that are primed and then dried, are less susceptible than undried primed seeds to environmental stresses with field plantings.

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