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Seed Priming Winter Wheat for Germination, Emergence, and Yield

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ABSTRACT

Insufficient stand establishment of winter wheat (*Triticum aestivum* L.) is a major problem in the low-precipitation (<300 mm annual) dryland summer fallow region of the inland Pacific Northwest, USA. Low seed zone water potential, deep planting depths with 15 cm or more soil covering the seed, and soil crusting caused by rain before seedling emergence frequently impede winter wheat stands. A 2-yr study involving laboratory, greenhouse, and field components was conducted to determine seed priming effects on winter wheat germination, emergence, and grain yield. Two cultivars were used because of their strong (Edwin) and moderate (Madsen) emergence capabilities. Germination rate was measured in the laboratory by 44 treatment combinations (two cultivars × three priming durations × seven priming media + two checks). Germination rate differed between cultivars as well as by priming duration, priming media, and concentration of priming media. The most promising laboratory treatments were advanced to greenhouse and field experiments where emergence and grain yield (field only) were measured in 10 treatments (two cultivars × four priming media + two checks) from wheat planted deep with 16 cm of soil covering the seed. In the greenhouse, seed primed in potassium chloride (KCl), polyethylene glycol (PEG), and water led to enhanced emergence of Madsen, but not of Edwin, compared with checks. Rate and extent of seedling emergence was greater for Edwin compared with Madsen irrespective of priming media in three of four field plantings at Lind, WA. None of the seed priming media benefited field emergence or subsequent grain yield in either cultivar compared with checks. Overall, results suggest that seed priming has limited practical worth for enhancing emergence and yield of winter wheat planted deep into summer fallow.

WINTER WHEAT–SUMMER FALLOW is the dominant rotation on 1.5 million hectares in the low-precipitation (<300 mm annual) dryland cropping region of the inland Pacific Northwest (PNW). Stand establishment of winter wheat planted into summer fallow is often hindered by dry seed zone conditions and is a crucial factor affecting grain yield (Bolton, 1983). Farmers place seed as deep as 20 cm below the preplanting soil surface with deep-furrow drills to reach adequate water for germination and emergence (Schillinger et al., 1998). Seed zone water content is the controlling factor for wheat seedling emergence, but soil temperature and depth of soil covering the seed are also important (Lindstrom et al., 1976; Kirby, 1993). In addition, farmers need winter wheat to emerge rapidly (7–10 d) because rain occurring after planting and before emergence causes surface soil crusting (Arndt, 1965). The emerging coleoptile or first leaf cannot penetrate such crusts.

In dry years, when seed zone water is inadequate, farmers will either plant shallowly (2–3 cm deep) into dry soil, delay planting until the arrival of rain in mid-October or later, or postpone planting until spring; all these practices reduce grain yield potential compared with planting early into stored soil water (Donaldson et al., 2001). In addition to increasing grain yield potential, successful early establishment of winter wheat on summer fallow provides protection from water erosion during winter (Papendick and McCool, 1994).

The three early phases of germination are: (i) imbibition, (ii) lag phase, and (iii) protrusion of the radicle through the testa (Simon, 1984). Priming is a procedure that partially hydrates seed, followed by drying of seed, so that germination processes begin, but radicle emergence does not occur. Methods of seed priming have been described in detail by Bradford (1986) and Khan (1992) and include soaking seed in water or osmotic solution, and intermixture with porous matrix material.

There are reports that hydration of seed up to, but not exceeding, the lag phase with priming permits early DNA replication (Bray et al., 1989), increased RNA and protein synthesis (Fu et al., 1988; Ibrahim et al., 1983), greater ATP availability (Mazor et al., 1984), faster embryo growth (Dahal et al., 1990), repair of deteriorated seed parts (Karssen et al., 1989; Saha et al., 1990), and reduced leakage of metabolites (Styer and Cantliffe, 1983) compared with checks. Priming of wheat seed in osmoticum or water may improve germination and emergence (Ashraf and Abu-Shakra, 1978) and promote vigorous root growth (Carceller and Soriano, 1972) under low soil water potential compared with checks. Osmotica that have shown good potential to enhance germination, emergence, growth, and/or grain yield of wheat include solutions of potassium hydrophosphate (KH_2PO_4) monobasic (Das and Choudhury, 1996), polyethylene glycol (PEG) (Dell'Aquila and Taranto, 1986), and potassium chloride (KCl) (Misra and Dwibedi, 1980). Water has also been used successfully as a seed priming medium for wheat (Harris et al., 2001).

The objective of our study was to evaluate the feasibility of seed priming for improving winter wheat production in the low-precipitation summer fallow regions of the inland PNW. Specific objectives were to determine the effectiveness of several priming media on germination, emergence, and grain yield of two soft white winter wheat cultivars in the laboratory, greenhouse, and under field conditions.

MATERIALS AND METHODS

Overview

A 2-yr experiment was conducted at Washington State University (WSU) from August 2000 to July 2002 to determine

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Abbreviations: C, cultivar; DAP, days after planting; PEG, polyethylene glycol; PD, planting date; PM, priming media; PNW, Pacific Northwest; RGP, radicle germination percentage; WSU, Washington State University.

seed priming effects on germination, emergence, and grain yield of winter wheat. The study involved laboratory, greenhouse, and field components. The two soft white winter wheat cultivars were selected on the basis of their strong (Edwin) and moderate (Madsen) emergence capabilities. Edwin (Jones et al., 2000) is standard height with club-type spike and long coleoptile, whereas Madsen (Allan et al., 1989) is semidwarf with common-type spike and medium-length coleoptile.

Newly harvested, untreated foundation seed was used both years. In August of 2000 and 2001, 250 g of seed of both cultivars was placed in 42 individual nylon net bags and immersed in liquid priming media. The seven priming media were: (i) water; (ii) 2% KCl (w/v); (iii) 4% KCl (w/v); (iv) 0.5% KH_2PO_4 (w/v); (v) 1% KH_2PO_4 (w/v); (vi) 10% PEG 8000 (v/v); and (vii) 20% PEG 8000 (v/v). All priming media were prepared in distilled water.

Seed was fully immersed in priming media at a temperature of 24°C for durations of 12, 24, and 36 h. The 24- and 12-h treatments were immersed 12 and 24 h after the first batch, respectively, so that all seed was removed from priming media at the same time. A nontreated check for both cultivars was also included. All seed was then rinsed thoroughly with distilled water and lightly hand dried using blotting paper. While still damp, seed (including check) was treated with [difenoconazole (R)-{(2,6-dimethylphenyl)-methoxyacetylamino}] propionic acid methyl ester fungicide at a rate of 0.65 mL kg^{-1} seed, then allowed to dry on paper towels at room temperature (24°C) until seed water content was 120 g kg^{-1} as measured with a grain moisture meter. Seed was stored at 24°C.

Laboratory Experiment

Laboratory research measured the rate of germination using a two-factor factorial completely randomized design (CRD) with 44 treatment combinations replicated four times. The two treatment factors were wheat cultivar (Edwin and Madsen) and priming duration and priming media [three priming durations (12, 24, and 36 h) $\times$ seven priming media (water, KCl- 2 and 4%, KH_2PO_4- 0.5 and 1%, PEG- 10 and 20%) plus a check. Fifty seeds from each of the treatments were placed on 90-mm-diam. Whatman No. 2 filter paper that was moistened with 10 mL distilled water in each glass 90-mm-inner diameter Petri dish. Seed was kept at 24°C air temperature under normal light. Radicle protrusion of 5 mm was scored as germination. Germination of individual seeds was measured at 12-h intervals and continued until no further germination occurred. The experiment was repeated in Year 2 (i.e., Run 2).

Greenhouse Experiment

The same seed lots used in the laboratory experiment were used in a greenhouse study. Two runs were conducted of a two-factor factorial experiment in a CRD with four replications. Factors were wheat cultivar (Edwin and Madsen) and priming media (water, KCl- 2%, KH_2PO_4- 0.5%, PEG- 10%, plus a check). Selection of greenhouse treatments was based on germination performance in Run 1 of the laboratory experiment. As germination was not affected by concentration of priming medium or duration of priming (result of Run 1 of the laboratory experiment), the low concentration of media with 12-h priming duration was selected for greenhouse and field studies.

The soil used was a Shano silt loam (coarse-silty, mixed, super active, mesic Xeric Haplocambids) with less than 10 g kg^{-1} organic matter in the surface 10 cm. Soil from the surface 15 cm of a summer-fallowed field was collected in early August 2000 and 2001 from the WSU Dryland Research Station at Lind, WA. Air-dried soil was placed in 19-cm-tall plastic pots with 18-cm diameter and gently tamped to create a 5-cm-deep soil layer with a bulk density of $\approx$1.25 Mg m^{-3}. The pots, which had small holes in the bottom, were placed in trays containing 5 mm standing water until soil was saturated. Pots were then removed from trays and kept on the greenhouse bench for 48 h until the soil water content was $\approx$0.15 kg kg^{-1}. Soil was made friable by scratching the surface with a 2-cm-wide table fork to a depth of 1 cm, then 100 seeds were hand-planted in each pot and covered with 1 cm of moist soil. Immediately thereafter, dry soil was added to each pot and gently pressed with fingers to create a 15-cm-deep dry soil layer with $\approx$1.00 Mg m^{-3} bulk density above the moist soil. Thus, there was 16 cm of soil (1 cm moist + 15 cm dry) covering seed that accurately simulated depth of planting under summer fallow conditions. Emergence was measured by counting all individual seedlings at 24-h intervals beginning 7 d after planting (DAP) and continued until no further emergence occurred.

Field Experiment

The field site was the WSU Dryland Research Station at Lind. Seed lots and treatments were the same as those used in the greenhouse study during both years. Experimental design was a three-factor factorial (wheat cultivar, priming media, and planting date) using randomized complete blocks with four replications. There were two dates of planting, the first and fourth week of September. Planting rate was 100 and 200 seeds row^{-1} (22.5 and 45 kg ha^{-1}) per individual 7-m-long plot in 2000 and 2001, respectively. A four-row deep-furrow split-packer drill with 38 cm row spacing was used for planting into summer fallow. A 16-cm-deep soil layer covered the seed.

Average annual precipitation at Lind is 243 mm. Crop year (1 September–31 August) precipitation during the experiment was 238, 211, and 220 mm for 2000 (fallow year for the 2001 crop), 2001, and 2002, respectively. Seed zone volumetric water content was measured in 2-cm increments to a depth of 22 cm from four locations within the experimental area on each planting date with an incremental soil sampler designed by Pikul et al. (1979). Emergence was measured by counting all individual seedlings from the two center rows at 11 and 20 DAP. Whole plots (all four rows) were harvested with a Hege 140 plot combine in July 2001 and 2002. Grain yield, adjusted to 120 g kg^{-1} moisture, was measured on a digital scale (0.1-g accuracy).

An analysis of variance for all data from laboratory, greenhouse, and field experiments was conducted by the PROC GLM procedure of SAS (SAS Inst., 1999). Treatments means were considered significantly different at $P < 0.05$. Mean separation was by Duncan Multiple Range Test.

RESULTS AND DISCUSSION

Laboratory Experiment

Radicle germination percentage (RGP), averaged across type of priming media, concentration of media, and duration of priming was consistently greater for Madsen than for Edwin in both runs (data not shown), but there was a strong run (R) $\times$ priming media (PM) interaction at 24-, 48-, and 72-h measurement intervals (Table 1a). There was also a cultivar (C) $\times$ PM interaction at 24 and 48 h (Table 1a), indicating variability in seed lots used in Run 1 vs. Run 2. Priming media were prepared by identical procedures for both runs and thus unlikely to be variable.

All priming treatments for Edwin had higher RGP than the check after 24 h in Run 1, whereas the check had greater or equal germination to all priming treatments after 24 h in Run 2 (Table 2). For Madsen, ten priming treatments had greater RGP compared with the check at 24 h in Run 1, but none of the priming treatments had greater RGP than the check in Run 2 (Table 2). Seed primed in water for 12 h had equal or better germination after 24 h compared with all other priming treatments for both Edwin and Madsen. Only three priming media for Edwin (12 and 24 h in KH_2PO_4 0.5%, and 24 h in water) had greater RGP than the Madsen check after 24 h.

Sixteen seed priming treatments for Edwin had greater RGP than the Edwin check at 48 h in Run 1, but none were superior to the check at 48 h in Run 2. For Madsen, the KH_2PO_4 1% 12 h was the only treatment with greater RGP than the check at 48 h in Run 1, and PEG 20% 12, 24 and 36 h the only treatments having greater RGP than the check in Run 2 (Table 2).

At 72 h, seven priming treatments had greater germination than the check for Edwin in Run 1, but none were higher than the check in Run 2. For Madsen, no priming treatment had greater RGP than the check at 72 h in either run (Table 2). This finding agrees with Salim and Todd (1968) and Harris et al. (2001) who also found that RGP was initially higher for primed wheat seed compared with the check, but differences diminished by 72 h.

Both cultivars showed no germination advantage, and sometimes a disadvantage, when seed was soaked in any of the priming media for more than 12 h. Similarly, higher concentrations of KCl, KH_2PO_4, and PEG generally did not benefit RGP (Table 2). Seed primed in KCl 4% solution showed low RGP irrespective of priming duration and cultivar, possibly due to a phytotoxic effect on the germinating embryo. Priming with water for 12 h was equal to or better than the other priming media tested for rapid germination.

Greenhouse Experiment

Seedling emergence through 16 cm of soil cover at 7, 9, and 11 DAP was always greater for Edwin compared with Madsen when averaged across all priming treatments (data not shown). Similar to the laboratory experiment, there was a highly significant C × PM interaction on all emergence count dates (Table 1b), providing further evidence of variability in seed lots in Run 1 vs. Run 2.

Priming media affected emergence of wheat cultivars differently. Edwin seed primed in water or KH_2PO_4 had enhanced emergence during both runs compared with KCl or PEG (Table 3). Emergence for the check, however, was equal to the best seed priming treatments. Final emergence from water- and KH_2PO_4-primed seed, and the check of Edwin was superior to KCl and PEG in both runs.

For Madsen, KCL- and PEG-primed seed had greater final (11 DAP) emergence than the check on both runs (Table 3). Water-primed seed had greater final emergence than the check in Run 2. The C × PM interaction suggests that change either in cultivar or priming media may affect seedling emergence. This interaction is particularly noticeable on the KH_2PO_4 effect on Edwin compared with on Madsen (Table 3).

Table 1. Analysis of variance for seed priming effects on two wheat cultivars for (A) Germination in laboratory, (B) emergence in greenhouse, and (C) field emergence and grain yield.

A. Germination (laboratory)				
Source	df	24 h	48 h	72 h
Run (R)	1	***	***	***
Cultivar (C)	1	***	***	***
Priming media (PM)	21	***	***	***
R × C	1	NS	NS	**
R × PM	21	***	***	***
C × PM	21	***	***	NS
R × C × PM	21	NS	***	NS
B. Emergence (greenhouse)				
Source	df	7 DAP	9 DAP	11 DAP
Run	1	***	***	***
Cultivar	1	***	***	***
Priming media	4	NS	NS	NS
R × C	1	NS	NS	NS
R × PM	4	NS	NS	NS
C × PM	4	***	***	***
R × C × PM	4	NS	NS	NS
C. Emergence and grain yield (field)				
		Emergence		
Source	df	11 DAP	20 DAP	Grain yield
Year (YR)	1	***	*	***
Planting date (PD)	1	**	NS	***
Cultivar	1	***	***	NS
Priming media	4	**	**	NS
YR × PD	1	NS	NS	***
YR × C	1	***	***	***
YR × PM	4	**	*	NS
C × PD	1	NS	NS	NS
PM × PD	4	NS	NS	NS
C × PM	4	NS	NS	NS
YR × C × PD	4	NS	NS	NS
YR × PM × PD	4	NS	NS	NS
YR × C × PM	4	*	NS	NS
C × PM × PD	4	NS	NS	NS
YR × C × PM × PD	4	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
NS = not significant.

Field Experiment

Seed Zone Water

Seed zone water content at early planting on 5 Sept. 2000 was 0.125 cm^3 cm^{-3} but the seed zone had dried to 0.111 cm^3 cm^{-3} water content by late planting on 26 Sept. 2000 (Fig. 1a). Drying of the seed zone from early-to-late September was even more pronounced in 2001 (Fig. 1b). This hastening of late summer seed zone water loss occurs as a result of the annual shift in the direction of coupled heat and water flows. Increasingly low night temperatures that occur in late summer rapidly reduce soil surface temperatures while higher temperatures exist at lower depths. Under these conditions, the vapor concentration gradient toward the soil surface is high and considerable soil water loss may occur (Hillel, 1971). This drying phenomenon is the reason why farmers plant winter wheat in late August–early September, particularly in dry years, in the eastern Washington wheat–fallow area. There is often insufficient seed zone water

Table 2. Seed priming effect on radicle emergence (germination) of two winter wheat cultivars at 24, 48, and 72 h after placement of seed in petri dishes in Run 1 and Run 2.

	Run 1			Run 2		
	Hours after placement of seed in petri dishes					
Cultivar–priming media	24	48	72	24	48	72
	% Radicle emergence					
Edwin						
Water 12 h	72 defgh†	79 fghijkl	85 fghijkl	77 abcdef	91 bcdefggh	94 abcdefghi
Water 24 h	83 abcde	83 defghijk	88 defghij	70 efghij	89 defghij	90 fghijkl
Water 36 h	72 defgh	73 klmn	84 ghijkl	72 bcdefghi	86 ghijklm	91 efghijk
KCL 2% 12 h	79 bcdefg	82 defghijk	86 efghijkl	72 bcdefghi	89 defghi	94 abcdefghi
KCL 2% 24 h	74 cdefgh	78 ghijkl	81 jklm	69 efghijk	87 fghijkl	90 ghijkl
KCL 2% 36 h	69 efgh	73 jklm	78 lmn	59 klm	72 nop	77 no
KCL 4% 12 h	47 i	55 o	73 mn	51 mno	67 pq	76 nop
KCL 4% 24 h	48 i	65 no	72 n	35 q	61 qr	71 op
KCL 4% 36 h	48 i	54 o	58 o	35 q	46 s	54 q
KH_2PO_4 0.5% 12 h	86 abcde	87 bcdefgh	92 abcdefg	73 bcdefghi	82 ijklm	89 hijkl
KH_2PO_4 0.5% 24 h	83 abcde	87 bcdefgh	91 abcdefgh	59 klm	79 lmno	86 kl
KH_2PO_4 0.5% 36 h	82 bcdef	83 defghijk	88 defghij	53 lmn	78 mno	85 lm
KH_2PO_4 1% 12 h	82 bcdef	84 defghijk	86 efghijkl	52 lmn	80 klmn	90 fghijkl
KH_2PO_4 1% 24 h	78 bcdefg	82 defghijk	86 efghijkl	49 mnop	84 hijklm	87 jkl
KH_2PO_4 1% 36 h	78 bcdefg	82 defghijk	88 defghijk	41 opq	73 nop	79 mn
PEG 10% 12 h	72 defgh	73 jklm	83 hijkl	82 abcd	92 abcdefg	93 bcdefghij
PEG 10% 24 h	74 cdefgh	76 hijklm	88 defghijk	67 fghijk	88 efghijk	92 defghijk
PEG 10% 36 h	76 cdefg	82 defghijk	93 abcdefg	67 fghijk	90 cdefghi	92 defghijk
PEG 20% 12 h	74 cdefgh	85 bcdefghi	89 cdefghij	76 bcdefg	95 abcdef	96 abcdefg
PEG 20% 24 h	76 cdefg	79 fghijkl	90 bcdefghi	81 abcd	94 abcdefg	95 abcdefgh
PEG 20% 36 h	58 hi	70 lmn	79 klmn	78 abcdef	93 abcdefg	96 abcdefg
Check	26 j	62 no	79 klmn	71 defghi	88 efghijk	97 abcde
Madsen						
Water 12 h	95 ab	96 abc	99 ab	83 ab	97 abcd	98 abcd
Water 24 h	88 abcd	93 abcd	98 abc	75 bcdefgh	94 abcdef	97 abcde
Water 36 h	70 efgh	74 ijklm	91 abcdefgh	72 dcdefghi	88 efghijk	92 cdefghiij
KCL 2% 12 h	86 abcde	90 abcdef	95 abcd	76 bcdefg	92 abcdefg	95 abcdefgh
KCL 2% 24 h	83 abcde	84 cdefghij	93 abcdefg	68 fghijk	91 bcdefgh	96 abcdef
KCL 2% 36 h	65 gh	73 klmn	88 defghijk	63 ijkl	86 ghijklm	95 abcdefgh
KCL 4% 12 h	26 j	31 p	82 ijklm	40 pq	71 op	79 mn
KCL 4% 24 h	29 j	30 p	73 n	35 q	58 r	70 p
KCL 4% 36 h	25 j	25 p	31 59	22 r	45 s	54 q
KH_2PO_4 0.5% 12 h	91 abc	96 ab	98 ab	75 bcdefgh	93 abcdefg	97 abcde
KH_2PO_4 0.5% 24 h	89 abc	89 abcdefg	94 abcdef	65 ghihk	93 abcdefg	95 abcdefgh
KH_2PO_4 0.5% 36 h	79 bcdefg	81 efghijkl	96 abcd	59 jklm	93 abcdefg	94 abcdefghi
KH_2PO_4 1% 12 h	99 a	99 a	99 a	76 bcdefg	96 abcde	97 abcde
KH_2PO_4 1% 24 h	90 abc	91 abcdef	95 abcd	59 jklm	92 abcdefgh	94 abcdefghi
KH_2PO_4 1% 36 h	82 bcdef	84 defghijk	95 abcd	43 nopq	81 jklmn	88 ijkl
PEG 10% 12 h	79 bcdefg	85 bcdefghi	93 abcdefg	82 abc	95 abcde	97 abcde
PEG 10% 24 h	89 abc	91 abcde	96 abcd	74 bcdefgh	94 abcdef	95 abcdefgh
PEG 10% 36 h	83 abcde	85 bcdefghi	98 ab	65 hijk	89 defghij	93 bcdefghij
PEG 20% 12 h	82 bcdef	88 abcdefg	95 abcd	87 a	99 a	100 a
PEG 20% 24 h	79 bcdefg	87 bcdefgh	95 abcd	79 abcde	98 ab	99 ab
PEG 20% 36 h	79 bcdefg	85 bcdefghi	98 abc	82 abc	98 ab	98 abc
Check	65 fgh	87 bcdefgh	98 abc	78 abcdef	89 defghi	100 a
Significance	**	**	**	**	**	**
CV%	17	11	7	12	7	5

** Significant at the 0.01 level.
† Within column means followed by same letter are not significantly different.

for emergence if planting is delayed until mid-to-late September.

Light rain just before planting on 5 Sept. 2000 and 26 Sept. 2001 created temporary surface soil wetting (Fig. 1a, 1b). Water from such rain showers quickly evaporates and does not benefit wheat emergence.

Emergence

A 10-mm rain occurred 5 d after the 5 Sept. 2000 planting at Lind, but soil crusting did not occur and seedlings emerged without undo difficulty (Table 4). Normally, as little as 3 mm of rain occurring after planting and before emergence will crust the surface soil so that wheat seedlings cannot emerge (Donaldson, 1996). As the wetting front from the heavy rain that occurred on 10 Sept. 2000 extended several centimeters into the soil, we hypothesize that wet soil may have provided physical support for the elongating coleoptile–first leaf and/or surface crusting did not occur until most seedlings had emerged. No other rain occurred for at least 15 d after the other plantings, thus soil crusting was not a factor.

There were relatively few emergence differences between cultivars or among priming media from either planting in 2000, whereas Edwin emergence greatly exceeded that of Madsen irrespective of priming media in 2001 (Table 4). These yearly differences are reflected in the YR × C interaction (Table 1c). The Edwin KCl treatment had greater emergence than its check at 11 DAP from the late planting in 2000, but KCl had no benefit over the check on any other measurement date in either year (Table 4).

Table 3. Seedling emergence of Edwin and Madsen through 16 cm of soil cover in the greenhouse as affected by priming media during two runs.

	Run 1			Run 2		
	Days after planting					
Cultivar–priming media	7	9	11	7	9	11
	% Emergence					
Edwin						
Water	69 ab†	71 a	75 a	60 ab	61 ab	64 a
KCl	56 bcde	58 bcd	59 bcd	49 bcd	51 bcd	52 bc
KH_2PO_4	71 a	73 a	74 a	61 a	62 a	63 a
PEG	55 cde	57 bcd	59 bcd	48 cde	51 bcd	52 bc
Dry check	68 abc	70 ab	72 a	59 abc	60 ab	62 a
Madsen						
Water	56 bcde	61 abcd	64 abc	49 bcd	53 abc	56 ab
KCl	53 de	62 ab	65 ab	47 de	55 ab	56 ab
KH_2PO_4	42 e	48 d	52 d	38 e	43 d	46 c
PEG	56 bcd	61 abc	66 ab	50 bcd	53 abc	58 ab
Dry check	44 de	49 cd	53 cd	40 de	44 dc	47 c
Sig.	**	**	**	**	**	**
CV%	17.1	15.0	12.6	15.2	12.9	10.7

** Significant at 0.01 level.
† Within column means followed by same letter are not significantly different.

For Madsen, none of the priming media enhanced emergence compared with the dry check in either year. Except for 11 DAP with the first planting date, emergence for water-primed Madsen was less than the check from both plantings in 2001 (Table 4).

Grain Yield

There were no grain yield differences between cultivars or among priming media except from the early 2001 planting where grain yields of Madsen primed with KCL and PEG were lower than any Edwin entries except KCL (Table 5). There were no within-cultivar grain yield differences (Table 5). Edwin was bred specifically for the low-precipitation environment, and its relatively higher grain yield compared with Madsen from the early 2001 planting may be partially due to better drought tolerance. The 2002 grain yield data agree with previous studies at Lind that show early planting generally increases grain yield compared with later planting dates (Donaldson et al., 2001). However, the YR × PD and YR × C interactions were highly significant (Table 1c). Grain yields for the dry checks were equal to or greater than any for the priming media.

SUMMARY AND CONCLUSIONS

Laboratory results showed that priming media enhanced germination during the first 24 to 48 h, but RGP of checks was generally equal to or greater than all priming treatments at 72 h. Water was equal to or more effective than any other priming media tested. Soaking seed for more than 12 h duration in any priming media tended to reduce rate and extent of germination, suggesting that optimum soaking time for wheat may be less than 12 h. Combined across priming treatments, Madsen germinated earlier than did Edwin.

Greenhouse data combined across priming treatments showed that Edwin always emerged faster and achieved greater final stand than Madsen. The Edwin check was equal to the best priming treatments for emergence. However, KCl- and PEG-primed Madsen (both runs) or water-primed Madsen (Run 2 only) had greater final emergence than the check. A strong cultivar × priming media interaction suggests the effect of priming media on emergence may be cultivar dependant; priming enhanced emergence of the cultivar with moderate emergence capability (Madsen) but not the cultivar with strong emergence characteristics (Edwin).

In the field study, seed zone water at time of planting was moderately dry in early September to dry in late September in both years. Rapid drying of the seed zone occurred between the first and fourth week of Septem-

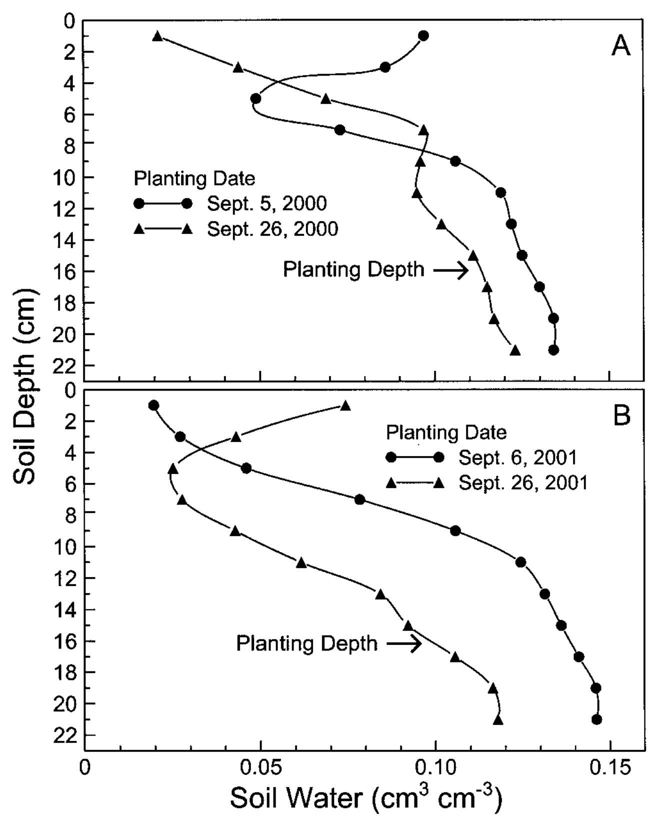

Fig. 1. Seed zone water content in summer fallow at time of planting in early and late September in 2000 (A) and 2001 (B) at Lind, WA.

Table 4. Emergence of two winter wheat cultivars as affected by priming media from four trials planted in the first and fourth week of September in 2000 and 2001 at Lind, WA.

	Year/planting date							
	2000				2001			
	1st week		4th week		1st week		4th week	
Cultivar–priming media	11 DAP	20 DAP	11 DAP	20 DAP	11 DAP	20 DAP	11 DAP	20 DAP
	% Emergence							
Edwin								
Water	45	50	46 ab†	48	49 a	56 ab	48 a	56 a
KCl	52	58	52 a	55	48 a	49 b	39 b	50 a
KH_2PO_4	39	42	39 bc	46	48 a	52 ab	48 a	52 a
PEG 8000	34	41	34 cd	41	51 a	54 ab	45 ab	54 a
Dry check	41	50	41 bc	48	55 a	58 a	51 a	54 a
Madsen								
Water	38	41	34 cde	45	15 b	26 e	4 e	26 c
KCl	34	43	30 def	47	19 b	34 d	9 de	30 bc
KH_2PO_4	28	36	24 f	38	22 b	39 cd	12 d	25 c
PEG 8000	35	43	25 ef	44	13 b	35 cd	11 d	29 bc
Dry check	41	50	37 cd	51	18 b	42 c	22 c	36 b
Significance	NS	NS	***	NS	***	***	***	***
CV%	27	24	17	21	20	12	16	13

*** Significant at the 0.001 level.
NS = not significant.
† Within column means followed by the same letter are not significantly different.

ber. Edwin seed primed with KCl had greater emergence than the dry check at 11 DAP during one year, but otherwise the check was equal to or better than any priming media for both Edwin and Madsen. Grain yield (averaged across cultivars and priming treatments) was greatest for late-planted wheat in 2001 and for early planted wheat in 2002. There was a strong YR × PD interaction. There were no within-cultivar grain yield differences in any of the four planting experiments.

In conclusion, although some priming media enhanced germination and emergence in the laboratory and greenhouse, there was little to no benefit for emergence or grain yield under field conditions. Thus, seed priming winter wheat appears to have limited practical value for promoting seedling emergence from deep planting depths in summer fallow. Breeding efforts to develop standard height and tall winter wheat cultivars with long coleoptiles continues to offer the best hope for farmers in dry summer fallow regions where emergence is a major concern.

Table 5. Grain yield of two winter wheat cultivars harvested in 2001 and 2002 (i.e., planted in 2000 and 2001) at Lind, WA, as affected by priming media and planting date.

	2001		2002	
	September planting date			
Cultivar–priming media	1st week	4th week	1st week	4th week
	Grain yield, kg ha^{-1}			
Edwin				
Water	1817	1784	3423 a†	2007
KCl	1829	2041	3097 abc	2113
KH_2PO_4	1433	2028	3331 ab	1775
PEG 8000	1567	1794	3372 ab	1840
Dry check	1778	2009	3427 a	1808
Madsen				
Water	1987	1878	3010 abc	1445
KCl	2164	2035	2864 c	1881
KH_2PO_4	1583	2059	2958 bc	1847
PEG 8000	1941	1947	2211 c	1442
Dry check	1631	1898	3242 abc	1637
Significance	NS	NS	*	NS
CV%	20.3	10.0	10.0	18.3

* Significant at the 0.05 level.
† Within column means followed by the same letter are not significantly different.

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