



# Rainfall Impacts Winter Wheat Seedling Emergence from Deep Planting Depths

William F. Schillinger\*

## ABSTRACT

Farmers in the low-precipitation (<300 mm annual precipitation) region of the Pacific Northwest (PNW) practice a 2-yr tillage-based winter wheat (*Triticum aestivum* L.)–summer fallow (WW–SF) rotation. Winter wheat is planted deep into moisture in late August or early September and seedlings emerge through 10 to 16 cm of dry soil cover. Rain showers that occur after planting create fragile soil crusts that the emerging first leaf often cannot penetrate. A rainfall simulator was used to conduct a five-factor factorial laboratory experiment to evaluate emergence of WW planted deep in pots. Factors were: (i) rainfall intensity and duration (1.25 mm/h for 3 h, and 2.50 mm/h for 2 h); (ii) timing of rainfall after planting (1, 3, and 5 d after planting + controls); (iii) cultivar (standard-height vs. semi-dwarf), (iv) residue on the soil surface (0, 840, and 1680 kg/ha); and (v) air temperature (21° and 30°C). The high-intensity rain caused a 2.3-fold reduction in emergence compared to the low-intensity rain. Emergence improved proportionally with increasing quantities of surface residue. The standard-height cultivar had four times greater emergence than the semi-dwarf. Air temperature and timing of rainfall had no significant effect on WW emergence. Results show that planting a WW cultivar with long coleoptile and first leaf as well as maintaining high quantities of surface residue to intercept rain drops will enhance WW stand establishment after rain showers to benefit both farmers and the environment.

A 2-yr WW–SF rotation is practiced on >90% of dryland crop hectares in the low-precipitation region of the PNW. The climate is Mediterranean-like with wet winters and dry summers. Whereas no-till fallow is successfully practiced in many regions of the world, farmers in WW–SF region of the PNW till the soil during the spring of the fallow year to break soil capillary continuity to best retain seed-zone soil water (Papendick et al., 1973; Wuest, 2010). Winter wheat seed is placed as deep as 20 cm below the pre-planting soil surface in late summer with deep-furrow drills to reach adequate water for germination, and seedlings emerge through 10 cm or more of dry soil cover (Schillinger et al., 1998). Although planting of WW into stored soil water in fallow is practiced in certain regions of Australia (Rebetzke et al., 2007) as well as numerous countries surrounding the Mediterranean Sea (Mahdi et al., 1998), nowhere else in the world is WW planted as deep as in the PNW. Due to the extreme depth of seed placement in the PNW, it is not the coleoptile that emerges from the soil but rather the first leaf after pushing through the tip of the coleoptile. The first leaf is thin, has weak structural support, is most often emerging under low soil water potential, lacks emergence force or lifting capacity (Arndt, 1965) and is therefore susceptible to kinking (resulting in no emergence) if it meets even slight surface resistance.

Farmers in the PNW plant into stored soil water in late August to early September because as much as 30% of total seed-zone water may be lost during the first 3 wk of September (Giri and Schillinger, 2003) due to a high vapor concentration gradient caused by increasingly low night temperatures that reduce soil surface temperatures while higher temperatures exist at lower depths. Grain and straw yield potential decline dramatically if adequate stands from planting into stored water cannot be achieved and seed must instead be “dusted in” at a shallow depth or planted after the onset of fall rains in mid-October or later (Donaldson et al., 2001). There are generally two scenarios where early-planted WW stands are not adequately achieved: (i) when seed-zone water potential is not sufficient for the elongating first leaf to reach the surface (Lindstrom et al., 1976) and (ii) when rainfall occurs after planting, but before emergence, causing the formation of a thin, fragile surface soil crust that the first leaf cannot penetrate.

There have been many studies conducted on soil crusting and its effect on crop seedling emergence (Baumhardt et al., 2004; Daba, 1999). Awadhwal and Thierstein (1985) provided an overview of this worldwide phenomenon. Structural soil crusts are formed when raindrops detach silt and clay-size particles from larger aggregates with these fine sediments then forming a thin, low-porosity layer on the soil surface. Subsequent soil surface drying, especially rapid drying with high air temperature under intense sunlight enhances formation of thin, rigid soil crusts (Taylor, 1962). Soils with silt as the dominant particle size (Bradford and Huang, 1992; Roth, 1992) and those with low organic matter content and low aggregate stability (Pikul and Zuzel, 1994; Singer and Warrington, 1992), such as those found throughout low-precipitation region of the PNW, have been identified as particularly susceptible to crusting.

Dep. of Crop and Soil Sciences, Washington State Univ., Dryland Research Station, P.O. Box B, Lind, WA 99341. Received 22 Oct. 2010.  
\*Corresponding author (schillw@wsu.edu).

Published in *Agron. J.* 103:730–734 (2011)  
Published online 10 Mar 2011  
doi:10.2134/agronj2010.0442

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**Abbreviations:** PNW, Inland Pacific Northwest of the United States; WSU, Washington State University; WW, winter wheat; WW–SF, winter wheat–summer fallow.

The objective of this study was to determine the effects of rainfall intensity, timing of rainfall after planting, cultivar, surface residue load, and air temperature on the emergence of WW from a deep planting depth. Due to the multiple factors and complexity of the study, the research was conducted under controlled laboratory conditions.

## MATERIALS AND METHODS

A laboratory experiment was conducted to determine impacts of rainfall on emergence of WW from deep planting depths. There were five factors:

1. Rainfall intensity and duration: 1.25 mm/h for 3 h and 2.50 mm/h for 2 h.
2. Timing of rainfall: 1, 3, and 5 d after planting + controls (i.e., no rain).
3. Winter wheat cultivar: Eltan (semi-dwarf) and Buchanan (standard-height).
4. Surface residue: 0, 840, and 1680 kg/ha.
5. Air temperature: 21°C (no sunlamp) and 30°C (with sunlamp).

Experimental design was a split-plot factorial (Steel et al., 1997) with one whole-plot factor (air temperature) and four subplot factors (rainfall intensity, timing of rainfall, cultivar, and surface residue) in a completely randomized layout. A total of 84 pots were required for each run of the study. These were: 2 rainfall intensities  $\times$  2 cultivars  $\times$  3 rainfall timings  $\times$  3 surface residues  $\times$  2 air temperatures + 12 controls (the controls were 3 surface residues  $\times$  2 cultivars  $\times$  2 air temperatures). Three separate runs were conducted, with each run serving as a replicate. Tukey's HSD test was used for comparisons between treatment means. Means were considered significantly different at  $P < 0.05$ .

### Preparing Pot Experiments

Soil used in the experiment was Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) with <1% organic matter. Shano silt loam soil, and its close relative the Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcic Haploxerolls), are the major soil types of the 1.22 million ha low-precipitation WW-SF region of east-central Washington. Soil textural size distribution of soils used in this study was 10% clay, 51% silt, and 39% fine sand. Shano soils lack structure and are highly susceptible to wind erosion when pulverized by excessive tillage and when residue cover is lacking. These soils contain significant quantities of fine particulates <10  $\mu\text{m}$  in diameter ( $\text{PM}_{10}$ ) that are readily suspended and transported long distances during windstorms (Sharratt et al., 2007).

Dry soil was collected from the surface 10 cm of tilled summer fallow at the Washington State University (WSU) Dryland Research Station in early September and sifted through a 6-mm mesh screen to remove clods and residue. Water content of the soil ( $\approx$  3% water by mass) was determined using the oven-drying method described by Topp and Ferre (2002). A measured mass of dry soil was placed in a slowly-revolving portable cement mixer and a pressurized backpack sprayer was then used to uniformly mist a known quantity of water into the mixer to achieve the desired soil water content of 11% by mass. One thousand grams of wetted soil was placed at the bottom of each 15-cm diam.  $\times$  18-cm tall pot and tamped to a depth of 5 cm to a bulk density of 1.25 g/cm<sup>3</sup> to achieve a volumetric soil water

content of 13.7%. The 13.7% volumetric soil water content is considered slightly greater than what is normally experienced in field conditions (Schillinger et al., 1998), but was deemed necessary because trial and error indicated that soil drying in pots occurred at a much faster rate than under field conditions (data not shown). A hand-held patterned dimpling device was then used to create 25 uniformly-spaced 6-mm deep indentations in the moist soil in which 25 seeds were placed. A mixture of 50 g wetted soil and 50 g field dry soil ( $\approx$  1.10 g/cm<sup>3</sup> bulk density) was then placed over the surface to cover the seeds. The remaining pot depth of 13 cm was loosely filled with field dry soil to a bulk density of  $\approx$  0.90 g/cm<sup>3</sup> and then leveled at the lip of the pot. These methods mimicked the soil conditions of deep-furrow planting of WW into tilled summer fallow.

Two WW cultivars were used on the basis of their strong (Buchanan) and moderate (Eltan) emergence capabilities. Buchanan (Donaldson, 1993) is a standard-height, hard-red, common cultivar with long coleoptile, whereas Eltan (Peterson et al., 1991) is a semi-dwarf, soft-white, common cultivar with medium-length coleoptile. Buchanan is renowned for its excellent emergence ability from deep planting depths. Due to its high grain yield potential, Eltan has been the most widely-planted cultivar in the WW-SF region of east-central Washington for the past 20 yr.

Standing stubble from WW grown at the WSU Dryland Research Station was allowed to weather in the field for 13 mo before being clipped into 5-cm long segments. The dry residue segments were spread uniformly on the surface soil of pots at rates corresponding to 0, 840, and 1680 kg/ha. All 84 pots in each run were prepared as described above within a 10-h time period.

### Rainfall Simulation

A Palouse Rainfall Simulator designed by Bubenzer et al. (1985) was used to simulate the low-intensity, small-drop-size rains typical in the PNW. The simulator was equipped with two independent rotating heads with two different nozzles. Model 2.8w and 4.3w wide-angle, full jet nozzles (Spraying Systems Co., Wheaton, IL) were fitted on the heads to deliver rainfall at 1.25 and 2.50 mm/h, respectively. The nozzles sprayed vertically downward at 100 kPa pressure with each head covering a 2.0-m diam. area. Heads were located 2.5 m above the surface to generate drop size and drop velocity similar to naturally-occurring, low-intensity rainfall common in the PNW. Median raindrop size diameter was 1.20 and 1.39 mm for the 1.25 and 2.50 mm/h delivery rates, respectively (McCool et al., 2009). The uniformity and intensity of rain distribution from both heads was verified by placing 10-cm diam. containers in a 30-cm grid under the entire catchment area. For both heads, there was <5% variability in uniformity of rain across the distribution area.

Selected pots were gently lifted from the laboratory bench and placed on a concrete floor under the two heads of the rainfall simulator on 1, 3, and 5 d after planting. The control pots received no rain.

### Seedling Emergence

Immediately after each of the three rainfall simulations, half the pots were kept on a laboratory bench at constant 21°C air temperature with the remainder placed in 90 by 90 cm wide, 40-cm tall cardboard boxes under a sunlamp. Air temperature

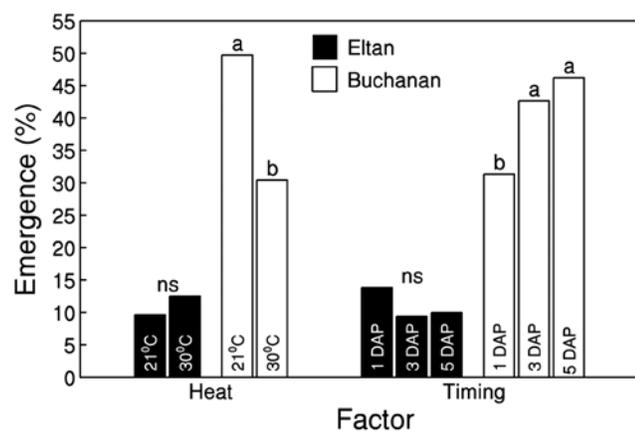
**Table 1. Analysis of variance for winter wheat seedling emergence as affected by five factors: air temperature (heat, H), rainfall intensity (R), rainfall timing (T), cultivar (C), and surface residue (Res).**

Source	df	Emergence
H	1	ns†
R	1	***
T	2	ns
C	1	***
Res	2	***
H × R	1	ns
H × T	2	ns
H × C	1	***
H × Res	2	ns
R × T	2	ns
R × C	1	ns
R × Res	2	ns
T × C	2	*
T × Res	4	ns
C × Res	2	ns
H × R × T	2	ns
H × R × C	1	ns
H × R × Res	2	ns
H × T × C	2	ns
H × T × Res	4	ns
H × C × Res	2	ns
R × T × C	2	ns
R × T × Res	4	ns
R × C × Res	2	ns
T × C × Res	4	ns
H × R × T × C	2	ns
H × R × T × Res	4	ns
H × R × C × Res	2	ns
H × T × C × Res	4	ns
R × T × C × Res	4	ns
H × R × T × C × Res	4	ns

\* Significant at the 0.05 level.

\*\*\* Significant at the 0.001 level.

† ns = not significant.



**Fig. 1. Individual cultivar response to air temperature (heat) and timing of rainfall. There were only two statistically significant interactions in the experiment out of 26 interaction possibilities. The significant interactions were timing of rainfall × cultivar and heat × cultivar. Timing of rainfall had no effect on the emergence of Eltan whereas emergence of Buchanan 1 day after planting (DAP) was reduced compared to rainfall 3 and 5 DAP. Similarly, heat had no effect on Eltan emergence, but did with Buchanan.**

within the boxes was kept at 30°C for 9 h during each 24-h period to simulate daytime field temperatures in early September.

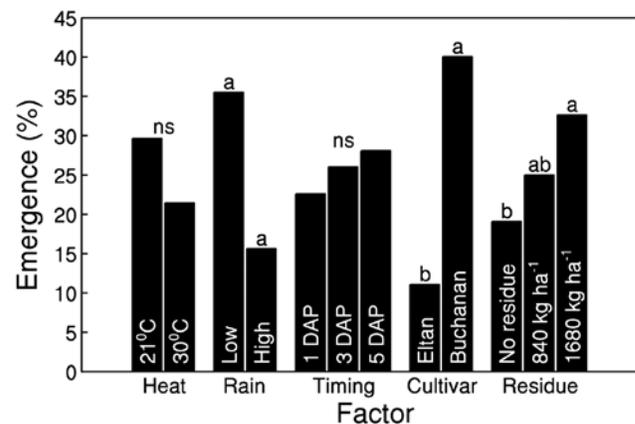
Attempts were made to measure soil penetration resistance with two different instruments in pots 6 d after planting. Both the Gilson Geotester dial penetrometer (Gilson Company, Lewis Center, IL) and the Soiltest CL-700 pocket penetrometer (Soiltest, Evenston, IL) were not sensitive enough to obtain viable readings in the extremely fragile crusts that formed on these soils.

The number of emerged seedlings in each pot was counted beginning 7 d after planting. Emerged seedlings were thereafter counted at 24-h intervals until 14 d after planting when no further emergence occurred.

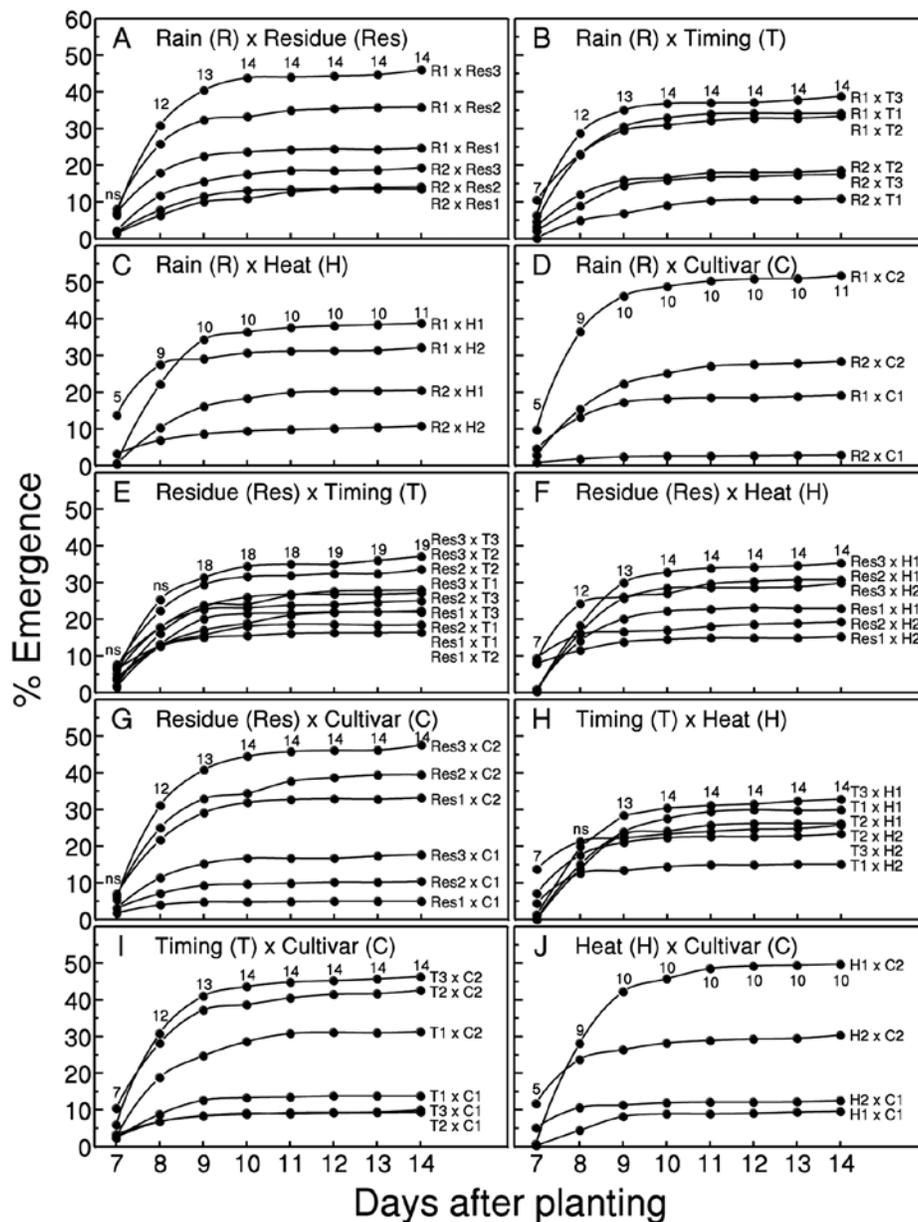
## RESULTS AND DISCUSSION

Rainfall intensity, cultivar, and surface residue had highly significant ( $P < 0.001$ ) impacts on seedling emergence (Table 1). Timing of rainfall and air temperature (heat) had no overall statistically significant effect on emergence. Among the five factors, the only interactions that occurred were timing of rainfall × cultivar and heat × cultivar (Table 1). These interactions are explained by the fact that: (i) Timing of rainfall had no effect on the semi-dwarf cultivar Eltan, whereas emergence was lowest in the 1 d after planting rainfall treatment for the standard-height cultivar Buchanan and; (ii) heat from the sunlamp had no effect on Eltan but reduced emergence in Buchanan (Fig. 1). The author has 25 yr of field and laboratory research experience with wheat and has never conducted a multiple-factor experiment with as few interactions as in this study; this indicating that experimental methods were kept very consistent for all three runs.

Final emergence as influenced by individual factors is shown in Fig. 2. Combined for the two cultivars, the high-intensity rain reduced emergence to 16% compared to 36% for the low-intensity rain. Emergence in the control pots averaged 86%. The standard-height cultivar Buchanan had a fourfold increase in emerged seedlings compared to the semi-dwarf cultivar Eltan. Surface residue benefited emergence, most likely by intercepting rain drops as described by Awadhwal and Thierstein (1985) and Baumhardt et al. (2004). Conservation tillage management systems to retain maximum quantities of surface residue during fallow have been developed (Schillinger, 2001),



**Fig. 2. Percent emergence of winter wheat planted deep into pots as affected by air temperature (heat), rainfall intensity, rainfall timing, cultivar, and surface residue. Data are the average from three runs. Winter wheat emergence in the control pots averaged 86%. DAP = days after planting.**



**Fig. 3. Percent emergence of winter wheat seedlings from 7 to 14 d after planting as shown by all possible two-way interactions of five factors. The five factors were: (i) air temperature (heat), (ii) rainfall intensity, (iii) rainfall timing, (iv) cultivar, and (v) surface residue. Numbers above the top data line in each subfigure indicate least significant difference at  $P < 0.05$ .**

and these methods are successfully practiced by many dryland farmers. Timing of rainfall had no significant effect on final emergence, but the general trend indicated that earlier rain is more detrimental for emergence than later rain, presumably because crust strength increased somewhat with time. Treatments subjected to 30°C air temperature under the sunlamp for 9 h/d showed emergence reduced by 30% compared to those held at constant 21°C, but these differences were not significantly different. This lack of statistical difference in WW emergence due to air temperature likely occurred because air temperature was the whole-plot factor in a split-plot design. The split-plot design provides increased precision for subunit comparisons (i.e., rainfall intensity, timing of rainfall, cultivar, and surface residue) but at the cost of lower precision for the whole-plot comparison, since the overall precision of the experiment will not be changed (Steel et al., 1997).

All possible two-way interactions of the five factors on seedling emergence from 7 to 14 d after planting are shown in Fig. 3. Emergence was always greatest for the low intensity rainfall treatments at all surface residue levels, and the presence of residue consistently benefited emergence (Fig. 3A). The timing of rain had no overall effect on emergence but the two intensities of rain were significantly different from each other (Fig. 3B). Similarly, the effect of rainfall intensity outweighed that of air temperature (Fig. 3C). Rainfall intensity caused emergence differences for both cultivars, but Buchanan had better emergence under both rainfall intensities compared to Eltan (Fig. 3D).

What could be described as a weakness in the methodology of this study is the fact that different intensity and volume of water were delivered from the two heads during rainfall simulation. Since 33% more water was applied in the high intensity rainfall treatment, intensity cannot be separated from the

volume issue. In retrospect, the low intensity treatment should have received rain for 4 h so that the total volume of water applied from both heads would be the same.

There was a general trend that the greater the surface residue, the better the emergence. This was the case with the relationships for residue  $\times$  timing of rainfall (Fig. 3E), residue  $\times$  air temperature (Fig. 3F), and especially for residue  $\times$  cultivar (Fig. 3G). Buchanan emergence was significantly greater than for Eltan with all residue levels (Fig. 3G), once more strongly indicating that the longer coleoptile and first leaf of standard-height cultivars significantly improve seedling emergence compared to semi-dwarf cultivars.

Air temperature appeared to be a slightly more important indicator of emergence than timing of rainfall (Fig. 3H). As previously discussed, the only statistically significant two-way interactions that occurred were timing  $\times$  cultivar (Fig. 1, Fig. 3I) and air temperature  $\times$  cultivar (Fig. 1, Fig. 3J). All three-way, four-way, and five-way interactions were not statistically significant (Table 1).

## CONCLUSIONS

Fragile soil crusts formed on silt loam soils after low intensity rainfall impede emergence of WW planted deep into summer fallow in eastern Washington. Crusts formed in this study were almost imperceptible and, although soil penetration resistance could not be measured with the available penetrometers, rainfall after planting had a marked negative impact on WW seedling emergence. Of the five factors evaluated, only cultivar selection and quantity of surface residue can be controlled by the farmer. Data conclusively show that when rainfall occurs after planting and before emergence: (i) the stand-height cultivar had an overall fourfold increase in seedling emergence compared to the semi-dwarf cultivar, and (ii) greater surface residue led to improved seedling emergence. These results bolster work currently in progress to enhance WW seedling emergence from deep planting depths through plant breeding and other research and extension efforts to promote the adoption of conservation-tillage summer fallow.

## ACKNOWLEDGEMENTS

Excellent technical support was provided by WSU Agricultural Research Technicians Timothy Smith and Steven Schofstoll. Funding was provided by the WSU Agricultural Research Center through Hatch Project 0250 and by USDA-NIFA through a Special Grant to the Columbia Plateau PM<sub>10</sub> Project.

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