Northwest Columbia Plateau PM_{10} Project

Objective 7: ***Identify Sustainable Farming Practices for the Columbia Plateau***

Title: ***Soil Water Content and Potential in the Seed Zone at the Horse Heaven Hills***

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Abstract of Research Findings

The Horse Heaven Hills (HHH) is the world's driest region for non-irrigated wheat farming with an average annual precipitation of 150 to 215 mm. Winter wheat-summer fallow helps to maintain a portion of over-winter precipitation for the successful establishment of winter wheat, which is usually planted into moist soil in late August. The HHH is often so dry that adequate seed-zone moisture cannot be maintained even with tillage-based summer fallow, and growers have to wait until the onset of rain in mid October or even later to plant winter wheat. In such years, growers would be better off practicing chemical fallow. The objectives of our study are: (1) to predict seed-zone water content and water potential in August based on the measured water content in March under conventional tillage and chemical fallow, and (2) to determine the critical water potential required for seed germination for selected winter wheat varieties. We collected weather data (for the period 2006 to 2010), soil samples, and residue data from conventional tillage and chemical fallow systems at two farms in the HHH. We evaluated physically-based water flow models, and we selected the Simultaneous Heat and Water (SHAW) model for modeling seed-zone water, because this model has provisions for an accurate surface energy balance and can incorporate surface residue layers. We parameterized the model with preliminary data available and performed initial model simulations. We also completed an experiment to determine critical water potentials for seed germination. Seeds of five cultivars of winter wheat (Buchanan, Eltan, Finley, Moro, Xerpha) with four replicates were tested at seven different water potentials. Seed germination results in combination with model simulations will help growers in deciding on the best tillage practices as well as optimal seeding time.

Objectives

Our specific objectives for this study are:

1. To predict seed zone water content and water potential in August based on measured water content in March under tillage fallow and no-till fallow, and
2. To determine the critical water potential required for seed germination for selected winter wheat varieties.

Methods and Materials

Field Experiments

On-farm experiments were conducted for five years each on two farms in the western and eastern part of the Horse Heaven Hills, denoted as the Eastern and Western Site, respectively. At each farm, tillage fallow (TF) and no-till fallow (NTF) plots, 61 by 18 m were set up each with four replicates. Total plot area at each site was 3.8 ha. In early April and again in late August from 2006 to 2010 at both sites, soil volumetric water content in the 30- to 180-cm depth was measured in 15-cm increments. Volumetric soil water content in the 0- to 30-cm depth was determined from two 15-cm core samples using gravimetric procedures. Seed-zone volumetric water content was determined in late August in 2-cm increments to a depth of 26 cm with an incremental soil sampler.

Characterization of Soil Properties and Residue Coverage

We collected soil samples (three replicates each) to determine soil properties, residue loads, and percentage residue cover. Undisturbed soil samples were collected at three representative depths (0–20 cm, 20–30 cm, and 30–40 cm) using a 5.7-cm inner diameter sampler. The TF plots had a loose soil mulch of 15 to 20 cm depth, and we inserted the sampler core by hand in order not to compact the soil.

Selected soil properties were assessed in the laboratory. The water retention characteristic was determined using the undisturbed cores. The hanging water column method was used for potentials > -100 hPa, followed by the pressure plate method for potentials between -100 and -5000 hPa, and dew point measurements for potentials < -5000 hPa.

On May 25, 2010, in situ measurements of field saturated hydraulic conductivity and near-surface hydraulic conductivity were conducted. We measured the field saturated hydraulic conductivity using a Guelph permeameter at a depth of 25 cm and 40 cm at each farm site. Standard protocol for use of the Guelph permeameter was followed. The surface hydraulic conductivity at -0.5 hPa was measured using a tension infiltrometer.

SHAW Modeling

The SHAW model was used to simulate soil water and temperatures for each site and treatment for the five years. For the numerical simulations, the soil was discretized into 22 nodes: 2.5-cm increments were used from the soil surface to 25 cm depth, 5-cm increments from 25 to 50 cm depth, and 30-cm increments from 50 to 200 cm depth.

Following the morphological description of the soils in the field, for the numerical simulation we considered the soil to have three layers (a tillage mulch or an upper A_p-horizon, a lower A-horizon, and a B-horizon). We simulated the dynamics of water and heat flow for each site and treatment from March to September for the years 2006 to 2010. This allows us to test the hypothesis that we can use SHAW simulations to predict late August water contents based on measured spring water contents. Simulations were run in forward mode, using the initial and boundary conditions as specified above. The simulated water contents for the planting dates were then compared with the experimental field measurements.

Germination Study

We studied five varieties of winter wheat (Triticum aestivum L.): Moro, Xerpha, Eltan, Buchanan, and Finley. The first three varieties are soft white winter wheats, the last two are hard red winter wheats. These varieties are some of the most common ones grown in the Pacific Northwest. Seeds have not been treated with any chemical and were not primed before use.

We used PEG to prepare a series of aqueous solution with water potentials of 0, -0.25, -0.5, -0.75, -1.0, -1.25, and -1.5 MPa. The amount of PEG to obtain these specific water potentials was determined based on a specifically developed calibration curve. Germination tests were carried out in a dark room at a controlled temperature of 18 to 20°C. Twenty seeds of each wheat variety were then placed onto a filter paper soaked with PEG.

We visually inspected the seeds every 12 hours for the first 7 days and every 24 hours afterwards to determine germinated seeds. Observations were continued until no germination occurred anymore or up to 50 days. The PEG solution was periodically added (1 mL/week) to maintain the required water stress. All treatments were replicated 8 times.

Seed germination data were analyzed by fitting a logistic equation:

$$P_t = \frac{n_t}{N} = \frac{1}{1+\exp(-a-b\ln t)} \qquad (1)$$

where n_t is the number of seeds germinated by time t, N is the total number of seeds germinated, a and b are fitting parameters, and P_t is the ratio of number of seeds germinated at time t and total seeds germinated.

The experimental design included two factors (5 varieties and 7 water potentials) and four replicates per treatment, resulting in a total of 4 x 5 x 7 = 140 tests. Analysis of variance was used to determine significant differences among the data at a confidence level of 5%. The data was analyzed in a Randomized Complete Block Design (RCBD) using Statistical Analysis Software (SAS).

Results and Discussion

Measured Water Contents

For both the Eastern and Western site, the TF consistently contained significantly more seed-zone water in late August than NTF. We illustrate this behavior with data from 2009. The drying front in the seed zone penetrated deeper into the soil under NTF than with TF (Figure 1). At the Eastern site, the TF at 20 cm depth had a soil water content of 0.12 m^3/m^3, whereas the NTF had a water content of 0.06 m^3/m^3. At the Western site, the TF at 20 cm depth had a soil water content of 0.09 m^3/m^3, compared to 0.05 m^3/m^3 for NTF. The near surface (0 to 10 cm) at all sites and treatments was very dry, with water contents less than 0.05 m^3/m^3.

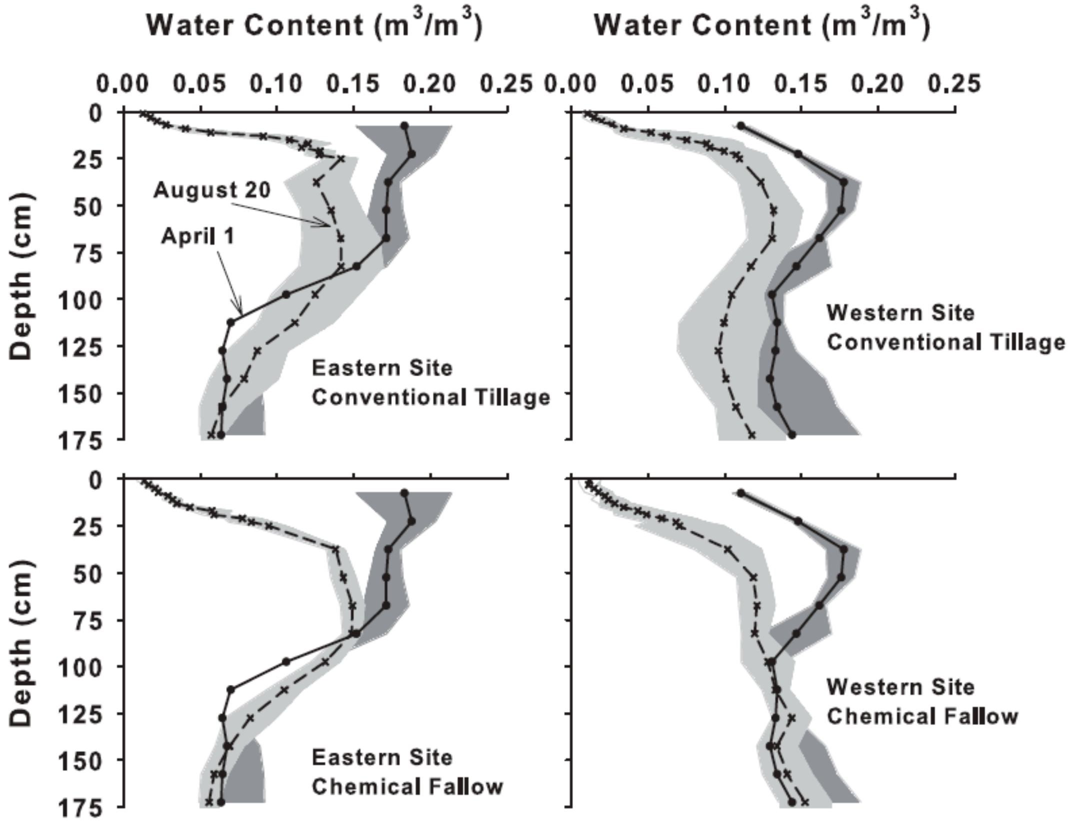

Fig. 1. Soil water profile just before tillage in spring (April 1, 2009) and at planting (August 20, 2009) for tillage fallow and no-till fallow treatments at the Eastern and Western Sites. Symbols indicate means and shaded area the standard deviations of the measurements.

The lower limit of the volumetric water content for winter wheat seed germination for a Ritzville silt loam soil in the Pacific Northwest is considered to be 0.11 m^3/m^3. At the Eastern site, the water contents with TF at 18 cm depth were greater than this threshold for seed germination at planting time in all five years of our study. In NTF, however, the water contents were less than this threshold in all five years. At the Western site in 2009, the water contents in TF at 18 cm depth were greater than the threshold for seed germination at planting time only in 2006. At the Western site, the water contents at 18 cm depth were 0.09 m^3/m^3 in TF and 0.06 m^3/m^3 in NTF, indicating that the water contents were below threshold and that planting needed to be delayed. At the Western Site, adequate seed-zone water for early planting could not be retained in four out of five years.

Weather Data and Soil Properties

Annual precipitation during the experimental period was less than the long-term average, except for the years 2006 and 2010 (Figure 2). The soil properties of the TF and NTF plots were similar, except for bulk density and hydraulic properties in the top 20 cm. The saturated water content was larger at the Eastern Site, which was expected based on the particle size distribution. The tilled layer of TF plots had a lesser bulk density than the NTF plots, resulting in a larger porosity and saturated water content. Other than the saturated water content, the water characteristics were similar among the sites**.**

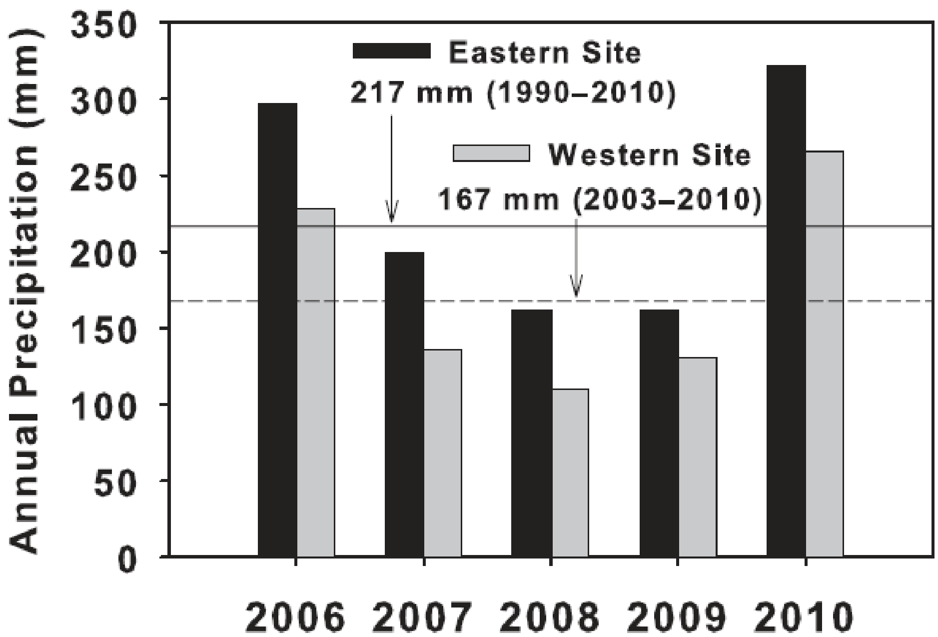

Fig. 2. Annual precipitation for 2006 to 2010 and long-term average annual precipitation (horizontal lines) at the Eastern and Western Sites.

Model Simulation Results

Figure 3 shows the simulated dynamics of the water content and water potentials between March and October of 2009 in the top 30 cm of the soil. The water contents and water potentials clearly reflect the drying of the soil profile during the course of the summer. The soil starts to dry from the top and the drying front moves downward during summer. Rainfall in May caused the water content to increase again, but then the water content continuously declined. Even a substantial rainfall of 4 to 5 mm in June did not elevate the soil water content noticeably. Most of this mid-summer rainfall penetrated less than 10 cm into the soil and was evaporated back into the atmosphere.

The measured water contents at the time of planting are depicted by the symbols in Figure 3 for the Eastern Site, the measured water content at 10 cm depth were drier than the ones simulated by the model. In the tillage plots, the water contents were 0.06 m^3/m^3 measured and 0.08 m^3/m^3 simulated, in the NTF plots, the water contents were 0.03 m^3/m^3 measured and 0.05 m^3/m^3 simulated. Water content at the 20 cm and 30 cm depths were underpredicted by the model simulations for the TF, and over predicted for the NTF. Differences between measured and simulated values were 0.03 to 0.02 m^3/m^3. For the Western Site, the model underpredicted the water content at 10 cm depth, particularly for NTF. The 20 cm and 30 cm depths were predicted well for TF, but overpredicted for NTF.

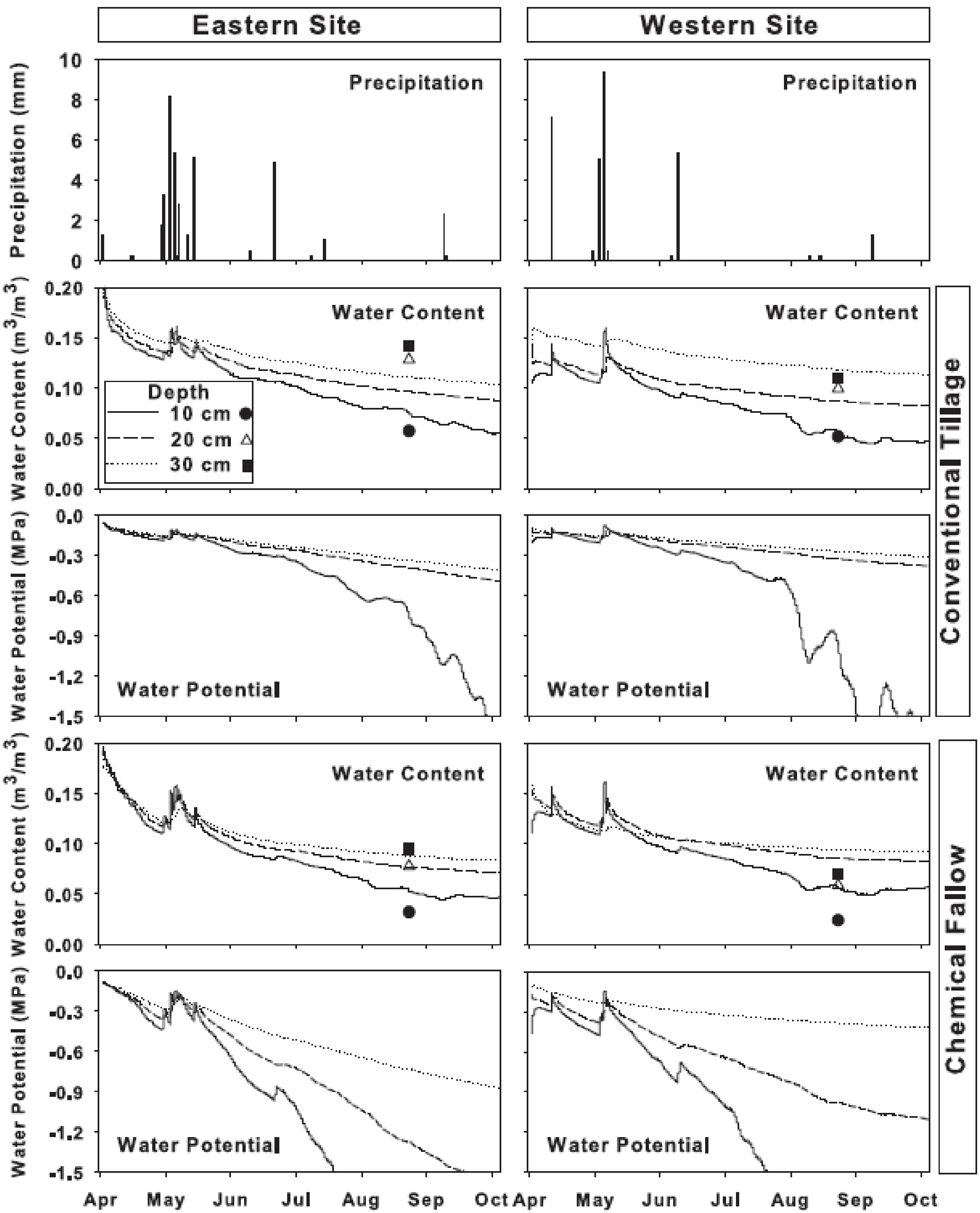

Fig. 3. Temporal dynamics of simulated water content and water potential in 2009 for tillage fallow and no-till fallow at the Eastern and Western Site. Symbols are observed water contents at three corresponding depths on August 20, 2009.

Depth profiles of water contents allow a good comparison of measured and simulated values. At the time of planting on August 20, 2009, the depth profiles of the simulated water contents followed the general trend of the observed data (Figure 4). The simulations could represent the drying of the seed zone in the TF well; however, for NTF, the simulations showed too steep a gradient in water content, i.e., the soil did not dry as deep compared to the measured water contents. Overall, the model was able to simulate the seed zone water (0 to 30 cm depth) more accurately for TF than for NTF, with the root mean squared error being 0.02 m^3/m^3 for TF and 0.017 m^3/m^3 for the NTF for the Eastern Site and 0.008 m^3/m^3 for TF and 0.025 m^3/m^3 for NTF for the Western Site.

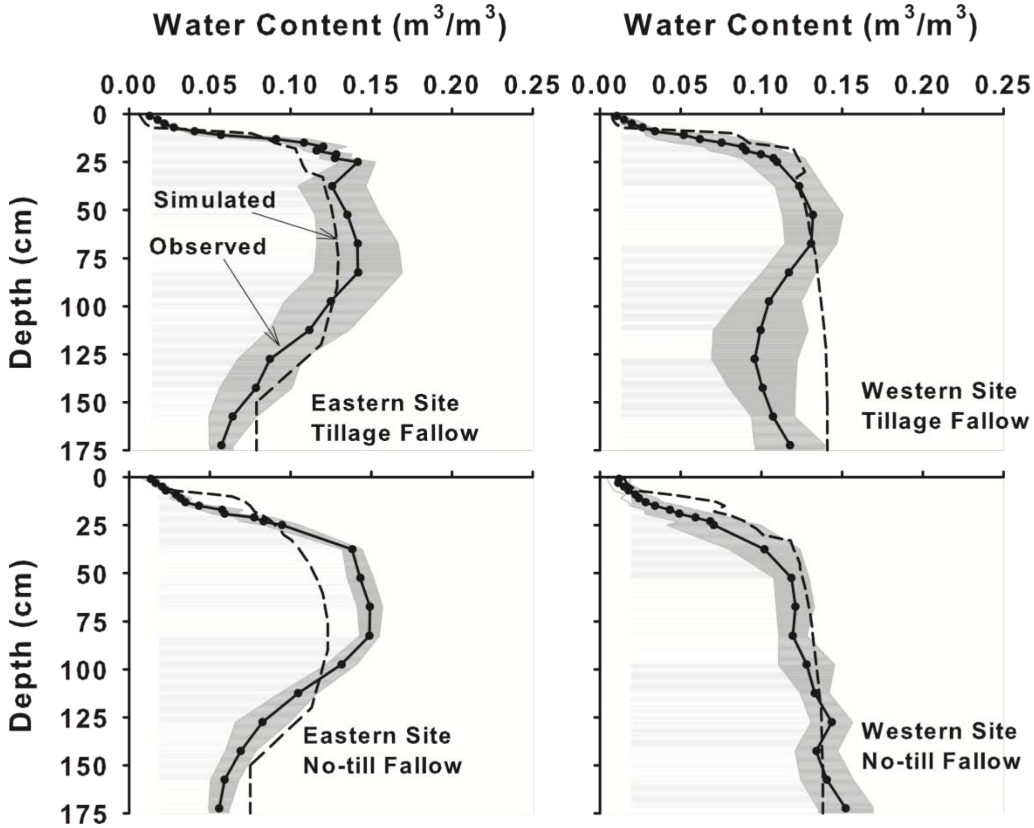

Fig. 4. Observed and simulated soil water profiles at planting (August 20, 2009) for conventional tillage and chemical fallow treatments at the Eastern and Western Sites. Observed data show means (circles) and standard deviations (shaded area) of measurements.

In general, the simulated total amounts of water in the top 30 cm of the soil in fall matched the measured amounts well (within a few millimeters of water storage) for all years of the experiment (Table 1) except on three occasions: NTF at the Eastern Site in 2007, TF at the Eastern Site in 2008, and NTF at the Western Site in 2009. As expected, the TF retained more seed zone water compared to NTF, and the simulations could represent the quantity of water accurately to within a few millimeters. The comparison of simulated and measured depth profiles of soil water contents followed a similar pattern for all years as for 2009, indicating that the model was able to capture the dynamics of the water flow in the soil for different weather conditions, although exact matching of the seed zone water contents were not possible at all times.

Table 1. Measured and simulated total soil water in the top 30 cm of the soil (cumulative amount of water in mm) under conventional tillage and chemical fallow at the Eastern and Western Site. Measured values are means and standard deviations.

Date	Tillage Fallow	No-till Fallow	Tillage Fallow	No-till Fallow
	Eastern Site		Western Site	
	mm			
August 25, 2006	27.4	22.5	27.6	21.4
Simulated	33.1	28.7	34.8	27.2
August 29, 2007	24.4	12.5	30.3	23.8
Simulated	23.4	20.6	28.8	22.4
September 3, 2008	27.9	19.7	23.7	21.2
Simulated	22.4	19.5	29.9	23.6
August 20, 2009	25.9	15.5	20.2	11.9
Simulated	23.2	20.6	26.1	20.3
September 8, 2010	26.3	24.7	23.6	22.4
Simulated	26.0	22.7	29.8	22.5

Germination Test

Each wheat varieties responded differently at each water stress. At low water stress (matric potential of 0 to -0.5 MPa), for each variety, total seed germination was more than 90%, but the time to reach at 90% seed germination varied. At high water stress (matric potential of -0.75 to -1.5 MPa), not only total seed germination varied among wheat varieties but the time to reach total seed germination also varied. As expected, the total seed germination was reduced as the water stress increased. Moro, soft winter wheat variety, had comparatively better seed germination at high water stress (Figure 5). We did not observe any seed germination for any wheat variety at matric potential of -1.5 MPa.

The seed germination data were analyzed with Equation 1 to determine the median germination time for each wheat varieties at each matric potential. Median germination times are shown in Table 2. Median germination times for each variety at first three water potentials (0, -0.25 and -0.5) were similar. Median germination times were subjected to analysis variance to test for the effect of matric potential. The observed total seed germinated data were also analyzed for the matric potential needed to reach 90% seed germination. For this analysis, we assumed that the matric potential at which the total seed germination is 90% or above is safe for a seeding decision.

Table 2. Median germination time (in days) for each variety at different water potentials.

Wheat Variety	Water Potential (MPa)						
	0	−0.25	−0.5	−0.75	−1.0	−1.25	−1.5
Buchanan	2.4	3.8	4.9	7.0	10.1	12.5	0
Eltan	2.5	3.8	5.2	7.8	10.6	12.5	0
Finley	2.7	4.0	5.2	8.2	10.9	13.7	0
Moro	2.6	3.8	4.8	7.2	8.9	12.5	15.1
Xerpha	2.6	3.9	5.2	8.0	10.3	11.9	0

Each wheat variety had 90% seed germination at a matric potential of -0.5 MPa but less than 80% at a matric potential of -1.0 MPa. Based on this result, we conducted another set of experiments to find the critical water potential for seed germination for wheat varieties. In this experiment we used PEG solutions with matric potential in the range of -0.5 to -1.0 MPa with an interval of -0.1 MPa. Experimental results suggest that the critical water potential for seed germination is at -1.0 MPa.

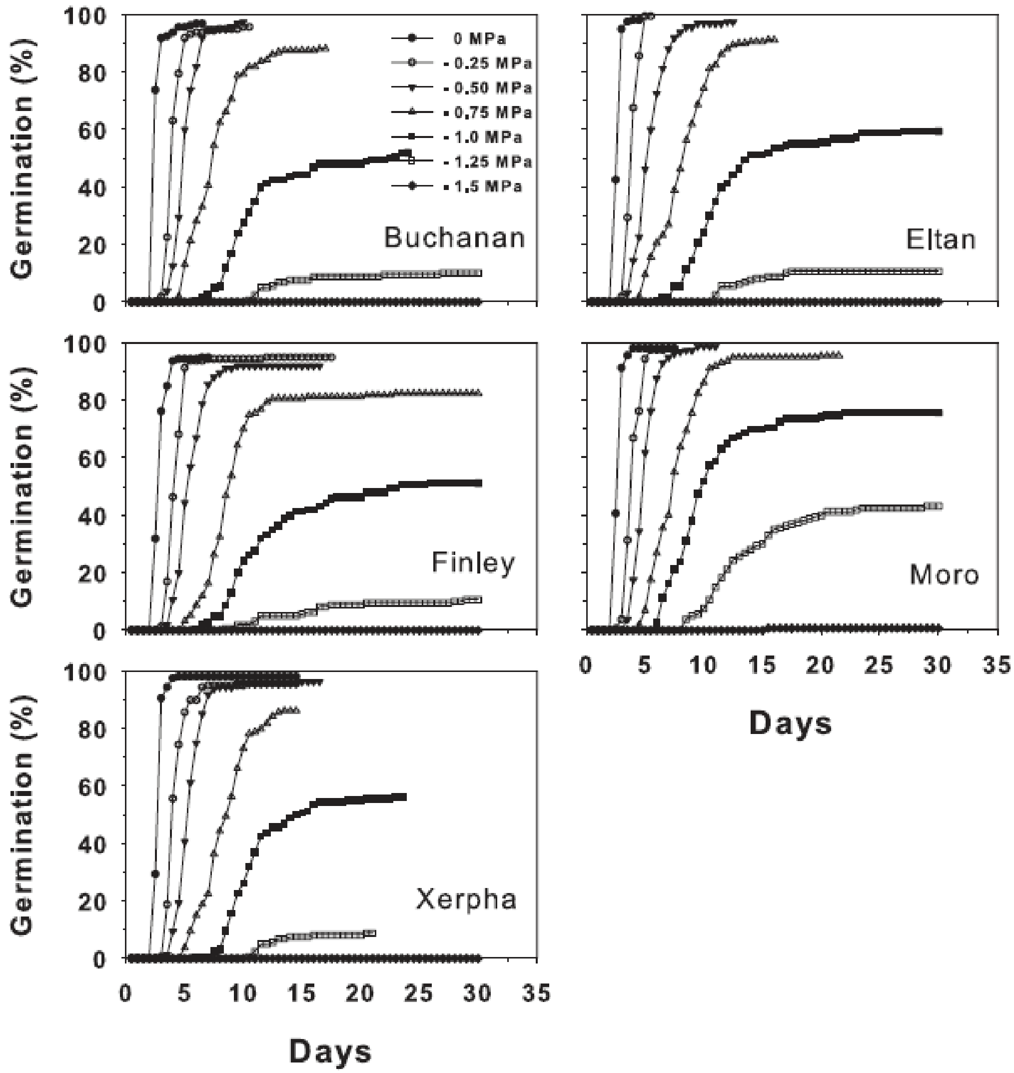

Fig. 5. Seed germination experimental results for five wheat varieties at seven different water potentials.

Publications and Presentations

Washington State University Field Day Abstracts

Abdou, H., P. Singh, M. Flury, and W.F. Schillinger. 2010. Critical water potential for wheat germination. p. 30. *In* 2010 Field Day Abstracts: Highlights of Research Progress. Technical Report 10-2. Department of Crop and Soil Sciences, Washington State University, Pullman, WA.