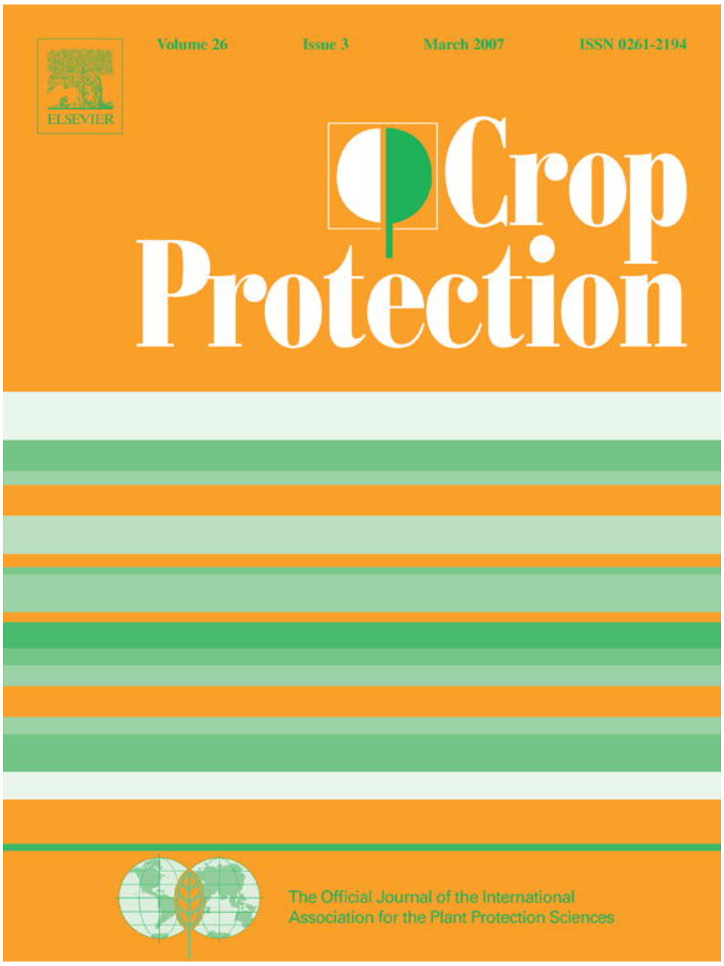
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Short communication

Spatially variable patterns of wild oat emergence in eastern Washington

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Abstract

Wild oat is one of the most economically important and widely distributed weed species in eastern Washington. The timing of wild oat control in this region is affected by the extreme topographical diversity. The objective of this research was to assess the influence of landscape diversity on the pattern of wild oat emergence. Wild oat emergence was monitored at five landscape positions along a north/south transect. The timing of emergence across the landscape tended to follow the distribution of solar radiation, such that wild oats emerged earlier at landscape positions with greater solar radiation and thus, higher soil temperatures. The time to reach 25% of maximum emergence was reached on average 17 days earlier at south- compared to north-facing landscape positions. This difference was maintained over the course of the emergence period. These results show that site properties, such as slope, aspect, and elevation, affect the thermal and hydric conditions in the soil seed bank and can cause site-specific patterns of wild oat emergence.

Keywords: Landscape; Microclimate; *Avena fatua*; Emergence

1. Introduction

Soil temperature and moisture conditions in the seed zone are primarily governed by seasonal climatic patterns. Seasonal changes in incident solar radiation, soil temperature, diurnal thermal amplitude, and soil moisture are environmental cues that regulate many of the stages of the annual plant life cycle, including dormancy release, germination and emergence. Factors such as soil type, landscape position, and cropping practices that disturb the soil surface can influence soil moisture and temperature in a site-specific manner.

On fields with minimal topographic relief, the seasonal pattern of incident radiation is relatively uniform across locations within a field. Soil water, however, can be influenced by spatial diversity in soil types or by slight changes in drainage patterns. For example, in Nebraska Dieleman et al. (2001) found an association between aboveground weed flora and the spatial variation in water-holding capacity. These authors also found that greater water availability during seedling establishment affected the abundance of weed species. The pattern of weed emergence is also influenced by the cropping system in practice (Yenish et al., 1992; Clements et al., 1996) and the size of the active soil seed bank (Zhang et al., 1998).

On complex landscapes, variation in slope, aspect, and elevation can affect seasonal and diurnal temperature and moisture conditions in the soil seed bank. Together with variations in soil type, these spatially variable factors can create a wide range of micro-sites that may result in site-specific patterns of weed emergence. Most research on the patterns of weed emergence has been conducted in fields with minimal variation in topography, and thus, information concerning the influence that landscape diversity may have on the pattern of weed emergence is lacking.

The Palouse region of eastern Washington is characterized by large rolling hills with spatially and temporally variable temperature and moisture conditions. It is a highly productive dryland agricultural region with emphasis on cereal production. Wild oat is one of the most economically

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important and widely distributed weed species in this region. Wild oat infestations are also a major problem in much of the arable land in North America and are especially difficult to manage in cereal crops such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) (Sharma and Vanden Born, 1978). Reported yield losses associated with wild oat competition range from 5% to 50% (Friessen and Shebeski, 1960; Bell and Nalewaja, 1968).

Wild oat control is complicated by intra- and inter-population variability in seed dormancy (Murdoch, 1998). As dormancy is alleviated, the 'emergence window' can extend from fall through early summer. Seedlings that emerge early in the spring may be controlled by a pre-plant herbicide application or tillage operation. However, later seedling cohorts, that emerge with the crop or shortly thereafter, will escape control unless a post-plant management strategy is implemented. In eastern Washington, a single Group I (ACCase inhibitor) or II (ALS inhibitor) herbicide is applied for early season post-plant wild oat control in cereal crops. Though a second application is possible, the cost is seldom justified by the yield benefit. If there is a single herbicide application, it is crucial that the herbicide application be made at that point in time that maximizes yield benefit. Therefore, understanding the timing and extent of wild oat emergence across the landscape could facilitate the optimal timing of weed control measures. The objective of this research was to quantify the influence of landscape diversity on the pattern of wild oat emergence in eastern Washington.

2. Materials and methods

Wild oat emergence was monitored at each of five landscape positions along a north/south transect on the Cunningham Agronomy Farm (46° 47′N, 117° 5′W) near Pullman, WA. Two positions faced north, two faced south, and one was located in the transect valley. The slopes at these locations ranged from 0% to 17%. Soils were predominantly silt-loam and correspond to the Palouse (Pachic-Ultic Haploxerol)-Thatuna (Oxyaquic Argixerolls)-Naff (Typic Argixerolls) association. During the fall of 2002, three 1-m^2 plots were established at each landscape position in a no-till winter wheat field. Residue from the preceding spring wheat crop was removed from all plots. Wild oat emergence was recorded weekly during the spring of 2003, and compiled as cumulative percent of final emergence, where the last day of sampling served as 100%. Statistical and regression analyses of emergence are described in Page (2004). At each landscape position, hourly soil temperatures were recorded at 2 cm depth using thermistors connected to a HOBO datalogger (Onset Computer Corporation, Bourne, MA) and volumetric water content was monitored in the top 5 cm of the soil profile on a weekly basis using a ThetaProbe (Delta T Devices, Cambridge, UK). Based on the volumetric water content, soil water potential was computed using an equation developed for no-till Palouse silt loam (Kenny, 1990). At each location, the potential global radiation per unit ground surface under clear sky conditions was calculated using the equations presented by Campbell and Norman (1998, Chapter 11), modified to account for variations in slope and aspect.

3. Results

The slope and aspect of each landscape position determine the solar irradiance, and thus, affect soil temperature and moisture variations. Our calculations show that the solar irradiance at the south shoulder position exceeds that received at the north shoulder position by an average of 10% during March, April, and May (Table 1). Over the course of a year, the potential radiation received across the landscape ranges from 7990 MJ/m^2 at the south mid-slope to 5790 MJ/m^2 at the north mid-slope position, assuming clear sky conditions. However, not all days meet this critical assumption. On average, 43% of the days of November, December, and January, are rainy. Thus, the approximate yearly solar radiation measured in Pullman (ca. 5300 MJ/m^2) is only 77% of the potential (A.R. Kemanian, unpublished data), which moderates the differences in solar radiation across landscape positions suggested by the calculations under clear sky, particularly in winter.

Landscape positions that differ in aspect (e.g. north- vs. south-facing positions) displayed the most marked difference in seasonal and diurnal temperature patterns. The daily maximum soil temperature at the south shoulder position was greater than at the north shoulder position by 2, 5.1, and 4.5 °C during mid-March, -April and -May, respectively (Table 1). Furthermore, the diurnal thermal amplitude at the south shoulder was greater than at the north shoulder position (Table 1). Thermal amplitude influences dormancy and stimulates germination in several weed species (Benech-Arnold et al., 1988; Martinez-Ghersa et al., 1997). However, cool, constant temperatures promoted greater germination in wild oat than higher, alternating temperatures (Carmona and Murdoch, 1995). The daily maximum and minimum soil temperatures differed little between the north shoulder and north mid-slope positions. In contrast, the maximum soil temperature at the south shoulder position exceeded that at the south mid-slope by 4.4 and 2.8 °C in mid-April and mid-May. While many of these observed temperature differences can be attributed to the disparity in incident radiation, the moisture content of the soil may also have influenced the daily maximum temperatures reached in the seed bank.

Variation in regional topography can influence the soil moisture conditions in the seed bank by determining the solar irradiance and by influencing the drainage patterns. Higher solar irradiance can cause higher soil temperatures and evaporation rates. The soil water potential at the south shoulder position decreased from −0.006 MPa in March to

Table 1
Seed bank microclimate conditions at the south shoulder (SSH), south mid-slope (SMS), valley (V), north mid-slope (NMS), and north shoulder (NSH) landscape position during the spring of 2003

Microsite conditions	SSH	SMS	V	NMS	NSH
March					
Potential solar radiation (MJ/m^2)	18.7	20.7	17.8	12.7	15.9
Mean soil temperature (C)					
Minimum	3.1	3.5	3.1	2.9	3.1
Maximum	10.1	9.8	9.5	8.1	8.1
Amplitude	7.1	6.3	6.4	5.3	5.1
Soil water potential (MPa)	−0.006	−0.005	−0.003	−0.004	−0.005
April					
Potential Solar radiation (MJ/m^2)	25.8	27.1	25.1	20.9	23.6
Mean soil temperature (C)					
Minimum	3.1	5.3	3.9	3.4	4.1
Maximum	19.0	14.6	15.3	14.4	13.9
Amplitude	15.9	9.3	11.4	11.0	9.8
Soil water potential (MPa)	−0.021	−0.021	−0.005	−0.014	−0.009
May					
Potential solar radiation (MJ/m^2)	31.0	31.6	30.6	27.9	29.7
Mean soil temperature (C)					
Minimum	5.3	6.5	5.6	6.5	6.2
Maximum	19.9	17.1	18.8	15.6	15.4
Amplitude	14.6	10.7	13.2	9.1	9.3
Soil water potential (MPa)	−0.089	−0.026	−0.011	−0.025	−0.025

Potential solar radiation values were calculated for the 15th of each month and soil water potential values were based on point samples taken on 12 March, 14 April, and 14 May, respectively. Mean soil temperatures represent the average of daily maximums and minimums from the 11th to the 18th of each month. Amplitude represents the difference between maximum and minimum soil temperatures.

−0.0089 MPa in May, while the water potential at the north shoulder position remained near field capacity over the same period (Table 1). Soil water potential also increased as elevation decreased, and was always greatest in the valley position. Thus, the combination of solar radiation and drainage patterns across the landscape creates a spatially and temporally diverse lattice of microsites differing in soil moisture conditions that may contribute to site-specific patterns of emergence.

Wild oat emergence occurred from early March through late May, although the timing of emergence differed notably among position on the landscape (Table 2). Initial wild oat emergence, as gauged by the time to 25% emergence (E_{25}), began on average 17 days earlier at south-facing positions than north-facing landscape positions (Table 2). We attribute the early wild oat emergence at south-facing positions to the higher soil temperatures relative to north-facing position. Emergence in the valley was also delayed relative to south-facing positions, but the reason for this delay is not clear since soil temperature and moisture conditions were similar to those at the south positions. South facing landscape positions also reached 50% and 75% emergence on average 15 days earlier than north-facing and valley positions, indicating that differences in the timing of initial emergence were maintained over the course of the emergence period. These results suggest that site properties, such as slope, aspect, and elevation, affect the thermal and hydric conditions in the soil seed bank and can promote site-specific patterns of wild oat emergence.

Table 2
Estimated time to 25% (E_{25}), 50% (E_{50}) 75% (E_{75}) emergence for the south shoulder (SSH), south mid-slope (SMS), valley (V), north mid-slope (NMS) and north shoulder (NSH) position in spring 2003

	SSH	SMS	V	NMS	NSH
	Day of year				
E_{25}	89	86	108	106	103
E_{50}	100	98	118	116	113
E_{75}	110	111	129	127	124

4. Discussion

While the Palouse region is distinguished as one the most productive dryland agricultural regions of North America (Papendick et al., 1985), its extreme landscape diversity poses immediate challenges for crop management. Farmers need to select weed management strategies that maximize economic return and minimize seed bank input. When weed emergence is extremely variable, both spatially and temporally, the process of selecting optimal weed control measures and timing is greatly complicated.

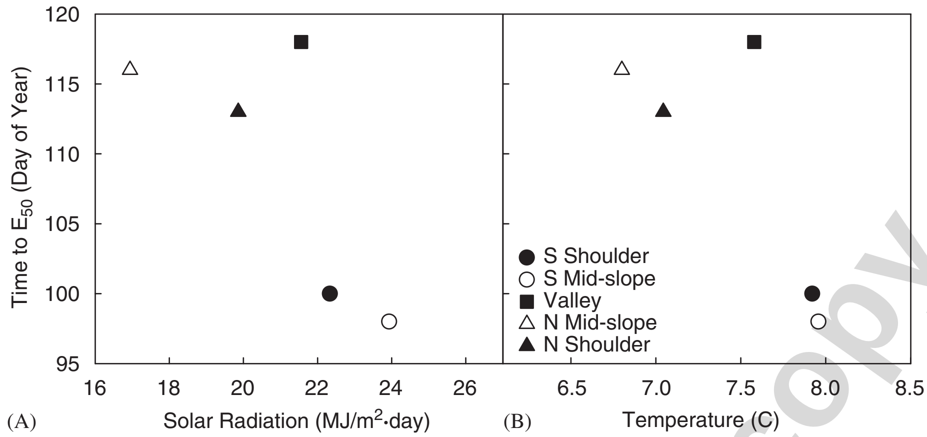

Fig. 1. Time to 50% wild oat emergence vs. (A) potential solar radiation and (B) soil temperature. Solar radiation and temperature values were averaged over March and April 2003.

Our results showed that wild oat emergence is strongly influenced by the site-specific environment. Temperature and moisture are particularly critical factors regulating seed germination and emergence (Forcella et al., 2000). In wild oat, germination increases with temperature, and is not precluded by low water until the water potential approaches −1.2 MPa (Fernandez-Quinantilla et al., 1990; Page, 2004). However, due to the genetic variation among geographically distinct populations the optimal parameters reported for wild oat germination differ among seed accessions (Sharma and Vanden Born, 1978; Fernandez-Quinantilla et al., 1990). Nevertheless, weed emergence models based on temperature and moisture parameters have been developed as decision aides to improve the timing and efficacy of control measures (Forcella, 1993; Harvey and Forcella, 1993). In regions with minimal topographic relief, hydrothermal models have demonstrated good potential for predicting the timing of weed emergence (Roman et al., 2000). However, our results suggest that in complex landscapes the input for such models should be spatially distributed to account for the variability in microclimate conditions across the field.

The patterns of emergence across the landscape tended to follow the distribution of solar radiation, such that wild oats emerged earlier at landscape positions with greater solar radiation (Fig. 1A) and thus, higher soil temperatures (Fig. 1B). However, the relatively slow emergence at the valley position was not consistent with this trend despite having intermediate levels of solar radiation and soil temperature. The valley position had higher soil water potential and dried out later in the spring than all other positions due to the drainage pattern of the landscape (Table 1). High soil water may reduce oxygen tension and slow weed seed germination and emergence (Forcella et al., 2000; Page, 2004). For example, germination of wild oat seeds was reduced from 90% to 10% after 9 h under anoxic conditions (Symons et al., 1986). Further research is needed to establish the effect of high moisture levels on the soil atmosphere at the valley position and on the germination and seedling elongation of wild oat.

Since wild oat emergence at all landscape positions tended to increase with increasing temperatures, and moisture was near field capacity during the emergence period, a thermal-based emergence model for predicting the timing of wild oat emergence in eastern Washington was developed based on 2 years of data (Page, 2004). Emergence was expressed against punctuated thermal time units (Finch-Savage and Phelps, 1993) that were cumulated based on the soil temperature and moisture measurements made at each landscape position. The timing and progression of wild oat emergence was markedly similar across the landscape when expressed against punctuated thermal time, and thus, a single Weibull curve was used to describe the emergence pattern. This empirical model explained much of the variability in wild oat emergence and further confirmed that the timing of wild oat emergence across the landscape was affected by site-specific microclimate conditions (Page, 2004).

The results of this study indicate that the timing of wild oat emergence in eastern Washington is strongly influenced by the diversity in micro-site conditions arising from the regional topography. Variability in the timing of wild oat emergence among landscape positions is likely an important factor contributing to the reduced efficacy of wild oat control measures on the Palouse. The impact of micro-site diversity on the pattern of wild oat emergence emphasizes not only the importance of considering the influence of site-specific processes on agricultural production, but also highlights the importance of assessing the full range of environmental conditions, including the extremes, when designing and implementing experimental designs, and when developing models to predict emergence.

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