Emergence Pattern of Five Weeds in the Central Great Plains[1]

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Abstract. Seedling emergence was characterized for five weeds that infest summer annual crops in the central Great Plains as affected by crop canopy or tillage. The study was established in winter wheat stubble between 1987 and 1990, with seedling emergence recorded weekly between April 1 and November 1. Kochia emerged primarily from early April to late June, whereas green foxtail, wild-proso millet, and redroot pigweed began emerging in late May and continued until August. Volunteer wheat emerged throughout the growing season. Tillage did not affect the emergence pattern of any species, but the numbers of kochia, volunteer wheat, and green foxtail seedlings were increased in no-till. Conversely, wild-proso millet emergence was greater with tillage. Only volunteer wheat's emergence was affected by crop canopy, as fall emergence of volunteer wheat was more than three times greater in corn than in proso millet. **Nomenclature:** Green foxtail, *Setaria viridis* (L.) Beauv. #[3] SETVI; kochia, *Kochia scoparia* (L.) Schrad. # KCHSC; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; volunteer wheat, *Triticum aestivum* L.; wild-proso millet, *Panicum miliaceum* L. # PANMI; corn, *Zea mays* L.
Additional index words: Crop canopy, temperature window, tillage, winter annual grasses, AMARE, KCHSC, PANMI, SETVI.

INTRODUCTION

Since the 1930s, winter wheat-fallow has been the prevalent cropping system in the semiarid central Great Plains. However, some producers are now cropping their land more frequently by inserting summer annual crops into the winter wheat-fallow rotation. For example, winter wheat-corn-fallow produced > 70% more grain than winter wheat-fallow per rotation cycle (24) and > 40% more profit (25).

Several reasons account for this change in cropping practices. Controlling weeds with herbicides rather than tillage during non-crop periods increases precipitation storage in soil (30), thus increasing available water for future crops. Secondly, fallow degrades soil quality by increasing erosion and loss of organic carbon and nitrogen (24). Cropping more intensively to minimize fallow protects the soil by increasing residue levels on the soil surface (25).

Crops adapted to this region include corn, sorghum [*Sorghum bicolor* (L.) Moench.], proso millet, foxtail millet [*Setaria italica* (L.) Beauv.], oat (*Avena sativa* L.) for forage, sunflower (*Helianthus annuus* L.), and safflower (*Carthamus tinctorius* L.) (4, 15, 20). Several of these crops, however, lack registered and effective herbicides for in-crop weed control. Because production of these crops is limited, it is not conducive for the chemical industry to invest resources in developing and registering new herbicides. Secondly, public environmental concerns may limit future options in the use of herbicides (21, 36).

Because of these limitations, producers will need integrated weed management systems (IWMS)[4] that are based on non-chemical control methods (26, 36). The foundation of IWMS is knowledge of ecological characteristics of weeds, such as life cycles and seedling emergence patterns (29, 34).

Weed species exhibit emergence periodicity, a period when seedlings typically emerge during the year (1, 11, 31). A knowledge of emergence periodicity can be used to plan preventive approaches for weed control (18, 34), such as altering planting date or crop choice. This approach has been demonstrated with weed community emergence. For example, if producers plant sunflower in place of safflower in northeastern Colorado, 80% of the weeds would emerge before planting sunflower (6). In contrast, over 70% of the weeds would emerge within 10 wk after planting safflower.

For crops with registered herbicides, such as corn or

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

[4]Abbreviations: IWMS, integrated weed management system.

sunflower, knowledge of emergence periodicity would enable growers to apply preemergence herbicides prior to emergence flushes. Also, producers could more accurately time postemergence herbicide applications to enhance weed control efficacy. Furthermore, bioeconomic models are being developed to minimize herbicide use in corn (19, 32). Subroutines in these models rely on weed seedling densities as the basis for initiating soil-applied or postemergence herbicide strategies. Thus, emergence patterns could guide timing of weed population assessment as well as spraying operations to ensure optimal effectiveness.

Emergence periodicity of selected species has been characterized for other locations, but species response may vary in different environments (11), or ecotypic differences may exist (1). Also, tillage and crop canopy can affect emergence characteristics (9, 13). For example, fewer wild oat plants (*Avena fatua* L.) emerged in barley (*Hordeum vulgare* L.) than in spring wheat during the growing season (33). In addition, weed species respond differently to levels of tillage, with no-till systems favoring proliferation of small-seeded species such as green foxtail, kochia, or downy brome (*Bromus tectorum* L.) (17).

This study was conducted to characterize the emergence of five weed species that infest summer annual crops in the central Great Plains, with the goal of supplying knowledge for producers to plan weed management strategies. A second objective was to evaluate the impact of tillage and crop canopy on emergence.

MATERIALS AND METHODS

Site description. Weed seedling emergence was recorded between April 1 and November 1 during 1987 to 1990 at Akron, CO. Study sites were established in stubble of winter wheat harvested the previous year. The site's production history was winter wheat-corn-fallow in a tilled system. Long-term yearly precipitation averages 419 mm, whereas precipitation averaged 368 mm from April 1 to November 1 during this study. Average daily air temperature (from U.S. Weather Bureau station, located within 0.5 km of site) increased approximately 1 C per week from 5 C in early April to 23 C in late July, then decreased to 5 C by late October. The soil was a Weld silt loam (Aridic Paleustoll), with 1.2% organic matter and a pH of 7.0.

Study procedures. *Crop canopy treatments.* Corn, sorghum, and proso millet were established in wheat stubble using prevalent cultural practices for this region (Table 1).

Table 1. Cultural practices for establishing corn, sorghum, and proso millet in wheat stubble.

Cultural data	Corn	Sorghum	Proso millet
Variety	P-3732[a]	P-8790	Cope
Planting date range	May 1–7	June 1–6	June 5–12
Seeding rate (plants/ha)	24,700	49,400	1.7 million
Row spacing (cm)	76	76	30
N fertilizer (kg/ha)	56	56	33
Harvest date range	Oct. 15–25	Oct. 15–25	Sep. 5–15

[a]P represents Pioneer Seeds.

Fallow was included as a fourth crop canopy treatment for a baseline comparison.

Tillage treatments. Two tillage systems were compared: no-till and conventional-till. The no-till system relied on repeat applications of glyphosate [*N*-(phosophonomethyl)glycine] for weed control during the period preceding crop establishment. Weeds were controlled in the conventional-till system (prevalent practice used by producers in this region) by sweep plowing as needed. The seed bed for the tilled crop canopy treatments was prepared by sweep plowing in late April. Study sites for each year were established in a different location in the same field.

Weed emergence data. The number of seedlings of each species was counted weekly in three 1-m^2 quadrats established in each crop canopy by tillage treatment, starting April 1 and continuing through October. After seedlings were counted, they were pulled and removed. Total seedlings per year ranged from 241 to 378/m^2, averaging 302 seedlings/m^2. The indigenous soil seedbank was the weed seed source.

Volunteer wheat emergence data. In 1987, we observed that the number of volunteer wheat seedlings emerging during August through October varied among crop canopies. To further quantify this effect, 50 winter wheat seeds were planted 2 cm deep in 1-m rows at three locations in each crop canopy by tillage treatment in 1988, 1989, and 1990. Simulated rainfall of 2.5 mm was applied to each 1-m row after planting. In earlier research, 2.5 mm of rain initiated fall germination of winter annual grasses (3). Winter wheat was planted bimonthly, beginning in August and continuing through October, resulting in six planting dates per year. Number of seedlings was recorded 21 d after planting.

Experimental design and analyses. A split-plot design was used, with crop canopy as the main plots arranged in a complete block design. Main plots were split by tillage. Each main plot was 24 m by 24 m, whereas tillage plots were 12 m by 24 m. Data were analyzed with years treated replications. The three subsample quadrats in each crop canopy by tillage treatment were averaged into one value for each week.

Emergence pattern for each species in each treatment was developed yearly by converting seedling emergence per week into a percentage of total emergence for the growing season. If analysis indicated that an interaction did not occur among tillage or crop, data were summarized over all treatments. Data over 4 yr were averaged by weekly intervals, with one standard deviation derived from yearly averages for each week. Emergence curves were developed by cubic spline interpolation[5].

For hand-planted winter wheat, means were averaged across planting dates to estimate crop canopy effect over the emergence period of winter annual grasses, mid-August to early November (5). Data were analyzed as a three-way factorial, with factors being year, crop, and tillage. If an interaction did not occur, data were averaged over the three factors.

For all analyses, if the F test was significant, then means were compared at the 5% level of probability.

RESULTS AND DISCUSSION

Species emergence patterns. Emergence pattern of individual species was not affected by crop canopy, except for volunteer wheat (to be discussed later), or tillage, nor were there any interactions among factors. Therefore, data were averaged over crop canopies and tillage to develop emergence curves. Each weekly data point represents 32 observations.

Kochia began emerging in early April, with 80% of the seedlings emerging between April 11 and June 20 (Figure 1a). Emergence showed four peaks, April 11, April 25, June 8, and August 22. The August emergence may appear to be anomalous, however, kochia emerging in late summer causes harvest difficulties with safflower in this region (2).

Initial emergence of green foxtail, wild-proso millet, and redroot pigweed began on May 23 (Figures 1b, 1c, and 1d). Duration of emergence was similar for the grasses, as over 90% of seedlings emerged between May 23 and July 25 for wild-proso millet and between May 23 and August 1 for green foxtail. Redroot pigweed, however, emerged over a longer period, as 90% of its seedlings emerged between May 23 and August 16, 2 to 3 wk longer than wild-proso millet or green foxtail.

Volunteer wheat emerged throughout the growing season. Most seedlings emerged in the fall, whereas the fewest seedlings emerged in early July (Figure 1e). This pattern of prolonged emergence, classified as continuous (27), explains why volunteer wheat is one of the more common weeds infesting summer annual crops in the central Great Plains (35). Volunteer wheat's pattern of emergence contrasts with the quasi-simultaneous pattern of the other four species, where a high percent of emergence occurred within a brief period of time (27).

Emergence pattern comparison with other locations. Ecotypes of weed species exist (1, 27), which may alter emergence characteristics among locations. Our data suggest ecotypes have developed for some species in our region. For example, kochia emergence in early August was not observed in Saskatchewan (8). Green foxtail emerged later in Colorado than at a cooler location in Minnesota, where initial emergence occurred in mid-April, 1 mo earlier (12). Redroot pigweed emergence differed between Colorado and Washington, emerging 1 mo earlier in Washington (23). Air temperatures during emergence at Washington indicate that redroot pigweed emerges at cooler temperatures at that location than in Colorado.

Temperature threshold for seedling emergence. If producers were able to predict when selected weeds emerge, they could manipulate cultural practices such as planting dates (6, 34) or crop rotations (18, 26) to disrupt weed growth and interference. Because the diversity of crop choices in the central Great Plains ranges from early spring crops such as oat to summer crops such as foxtail millet, this diversity provides producers with options to minimize weed densities in the crop.

Prediction of weed emergence requires knowledge of environmental factors governing germination. Roberts (28) suggested that initial seedling emergence is governed by a temperature threshold, such that when air temperatures reach a specific level, seedling emergence begins if moisture is available. Stoller and Wax (31) also suggested a temperature threshold; however, they found that heat unit accumulation did not correlate with seedling emergence. Egley (10) reported that amplitude of daily temperature fluctuation was most accurate in describing the temperature effect on seedling emergence.

We calculated the daily air temperature fluctuation during the 7-d period before each species began to emerge, and averaged the values over all years. When kochia began

[5]SigmaPlot. Jandel Scientific, San Rafael, CA 94901.

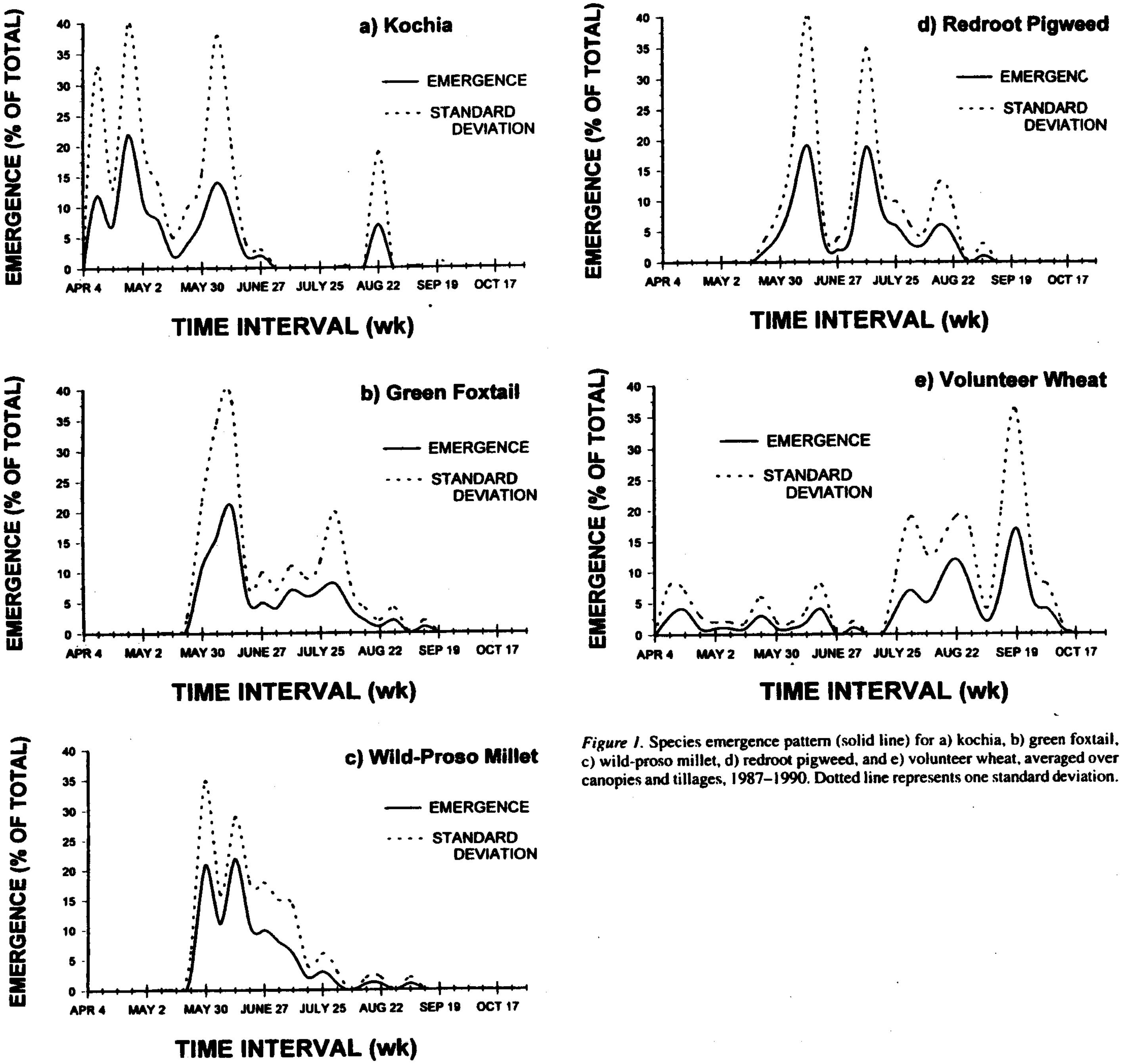

Figure 1. Species emergence pattern (solid line) for a) kochia, b) green foxtail, c) wild-proso millet, d) redroot pigweed, and e) volunteer wheat, averaged over canopies and tillages, 1987–1990. Dotted line represents one standard deviation.

emerging, minimum and maximum temperatures were 2.2 and 17.2 C, with the daily average being 9.5 C (Table 2). For green foxtail, wild-proso millet, and redroot pigweed, minimum temperature ranged from 8.3 to 9.5 among the three species, whereas maximum temperatures ranged from 22.2 to 25.0 C, for the 7 d preceding initial emergence. Air temperature fluctuation for volunteer wheat was not calculated because of its continuous emergence. With these temperature values, producers can predict initial seedling emergence of these weeds and plan preventive management strategies.

Tillage effect on emergence. In our study, tillage influenced the magnitude of seedling emergence, but not the emergence pattern of any species (data not shown). Be-

Table 2. Daily average, minimum, and maximum air temperatures (± one standard deviation) for the week preceding initial emergence of four annual weed species during 1987 to 1990.

Species	Air temperature		
	Average	Minimum	Maximum
	C		
Kochia	9.5 ± 4.3	2.2 ± 4.6	17.2 ± 4.8
Green foxtail	16.7 ± 2.6	8.3 ± 1.8	24.5 ± 3.2
Wild-proso millet	17.2 ± 1.9	9.5 ± 1.8	25.0 ± 2.8
Redroot pigweed	15.0 ± 1.2	8.9 ± 1.4	22.2 ± 1.2

cause tillage and crop canopy did not interact, data were averaged over crop canopies.

The no-till system increased kochia, volunteer wheat, and green foxtail emergence, with kochia emergence increasing almost 4-fold (Figure 2). Volunteer wheat emergence was tripled in no-till, but tillage in the previous fall may have stimulated fall emergence (7), thus depleting the seedbank in the tilled plots the following year. Green foxtail emergence was increased 1-fold with no-till.

In contrast, wild-proso millet emergence was 50% greater with tillage, whereas redroot pigweed emergence was not affected by tillage (Figure 2). Our data show that tillage effect on seedling emergence is species-related, as reported previously (11, 13). However, tillage effect on a species population at a cropping system's level appears to interact with other factors. Using green foxtail as an example, this species has been observed to increase in both no-till and till production systems, when compared among several locations (22). Furthermore, in a 20-yr rotation study in Saskatchewan, green foxtail densities in spring wheat were not affected by tillage (16), again emphasizing that other factors in addition to tillage determine weed population dynamics.

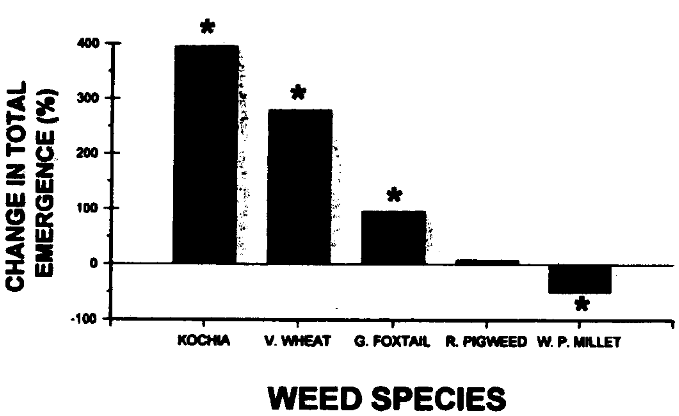

Figure 2. Effect of tillage on the magnitude of seedling emergence of five species. Data means represent yearly seedling emergence in the no-till system, averaged over all crops, and are compared to emergence in the till system. Asterisk indicates that the no-till mean for a species was significantly different compared to its mean in the till system.

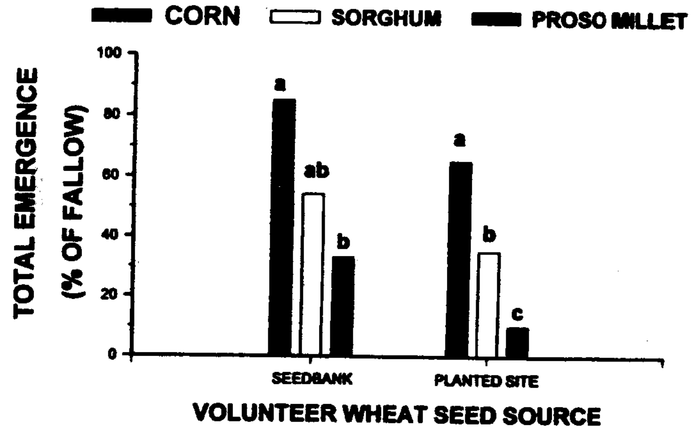

Figure 3. Effect of crop canopy on seedling emergence of volunteer wheat from soil seedbank and hand-planted sites. Data from each crop were averaged over tillage systems and compared to the fallow treatment for the period from August 1 to October 31. Canopy means were separated by the Duncan's New Multiple Range Test.

Crop canopy effect on emergence. Only volunteer wheat emergence was affected by crop canopy. Averaged over tillage systems, emergence from the soil seedbank during August through October was three times greater in corn than in proso millet (Figure 3). Volunteer wheat emergence in sorghum was intermediate. This canopy effect also was observed with the hand-planted treatments: for every seedling that emerged in proso millet, approximately three and seven seedlings emerged in sorghum and corn, respectively.

Several factors may be involved in stimulating germination in different crop canopies, including soil moisture level (28, 31), solar radiation reaching the soil surface (26, 37), air temperature amplitude (10), and allelopathy (1). In addition, the crop's rooting pattern near the soil surface may contribute to emergence differences. Compared to the distribution of corn roots, sorghum roots are more concentrated near the soil surface than corn and can extract more water from the upper levels of the soil profile (14). Because of this rooting difference, soil in the sorghum canopy dries out sooner, which may reduce seedling emergence. Proso millet root distribution is similar to sorghum, which may contribute to reduced seedling emergence in proso millet.

Wheat producers face three difficult-to-control winter annual grass weeds in winter wheat: volunteer rye (*Secale* *cereale* L.), jointed goatgrass (*Aegilops cylindrica* Host), and downy brome (7). One control strategy is to insert summer annual crops into the rotation because this strategy will lengthen the time before the next wheat crop and thus favors the depletion of the soil seedbank.

Fall emergence patterns of volunteer wheat, downy brome, and jointed goatgrass are almost identical in northeastern Colorado (5). Therefore, our data suggest that corn, compared to proso millet, would stimulate more seedlings of winter annual grasses in the seedbank to emerge. Preliminary research with jointed goatgrass and downy brome supports this hypothesis (7). By stimulating winter annual grasses to emerge in corn during the fall, producers can control these seedlings after corn harvest and enhance seedbank depletion before the next wheat crop.

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