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Ecology and Interference of Proso Millet (*Panicum miliaceum*) in Semi-Arid Corn[1]

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Abstract: Producers in the semi-arid Great Plains are starting to grow corn in sequence with winter wheat and proso millet. However, volunteer proso millet (hereafter referred to as proso) is difficult to control in corn with conventional practices. This study characterized growth and interference of proso in corn to aid producers in developing control strategies. Proso seedlings began emerging May 18 with 78% of seasonal emergence occurring by June 22; initial proso emergence occurred within 2 wk of corn emergence in all years. Seed production was related to time of emergence; proso seedlings emerging in mid-May produced approximately 2,800 seeds per plant, whereas seedlings emerging 4 wk later produced 88% fewer seeds. Controlling proso in late June prevented loss of corn grain yield caused by competition. When corn was planted in early May, the height difference between corn and proso was sufficient to allow postemergence-directed applications of graminicides for proso control. Corn yield was highest when planted in early May.

Nomenclature: Proso millet, *Panicum milaceum* L. #[3] PAMIL; corn, *Zea mays* L. 'Pioneer hybrid 3732'; wheat, *Triticum aestivum* L.

Additional index words: Critical period of interference, emergence period, transgenic corn, PAMIL.

Abbreviations: GDD, growing degree days.

INTRODUCTION

Producers in the central Great Plains are changing their crop rotations because of improved water-use efficiency of crops in no-till systems (Peterson et al. 1996). Rotations such as winter wheat–corn–proso millet or winter wheat–corn–proso millet–fallow can nearly double land productivity compared with the conventional rotation of winter wheat–fallow (Anderson et al. 1999; Peterson et al. 1993). Because precipitation in the semiarid Great Plains is so erratic, producers consider soil water levels during the spring before making crop choices. This approach has led producers to plant corn after proso if soil water level is high, which results in volunteer proso infesting corn.

The prevalent herbicide used in semi-arid corn is atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine]; however, proso is tolerant of atrazine (Anderson and Greb 1987). Proso can be controlled with other residual herbicides (Westra et al. 1990), but these herbicides often limit cropping flexibility because of carryover injury and label restrictions. Furthermore, producers operate within a narrow profit margin that may restrict residual herbicide options.

Producers also can control proso with postemergence herbicides. For example, nicosulfuron {2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N, N*-dimethyl-3-pyridinecarboxamide} controls proso in corn when applied postemergence (Tapia et al. 1997). Development of transgenic crops (Kishore et al. 1992) allows producers to apply sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} or glyphosate [*N*-(phosphonomethyl)glycine] to corn for proso control (Kleppe and Harvey 1991). In addition, paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) and several graminicides will control proso without injuring corn if applied postemergence-directed (Fawcett and Harvey 1988; Kleppe and Harvey 1991). Using postemergence herbicides to control proso allows producers to maintain cropping flexibility in future production decisions.

Postemergence herbicide activity is influenced by several factors. For example, grasses are less susceptible to graminicides when tillering compared with earlier development (Neal et al. 1990; Schreiber et al. 1979). Also, proso height at time of application influences herbicide performance. Nicosulfuron activity is reduced 50% when

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

proso is 15 to 25 cm tall compared with plants 10 cm tall or less (Tapia et al. 1997). Postemergence-directed technology is predicated upon a height differential: it is most effective when corn is at least 40 cm tall and proso is less than 15 cm tall (Fawcett and Harvey 1988). A further consideration with postemergence herbicides is the critical period of interference, defined as the period of time that weeds compete with corn without causing yield loss (Carey and Kells 1995; Hall et al. 1992). If herbicides are applied too early or too late, crop yield can be reduced by weed interference.

Producers are concerned about herbicide resistance. In the Great Plains, herbicide-resistant weeds such as kochia [*Kochia scoparia* (L.) Schrad.] and Russian thistle (*Salsola iberica* Sennen & Pau) are now common (Lyon et al. 1996). One strategy to manage herbicide resistance is to diversify control practices and rotate herbicides with different modes of action (Holt and LeBaron 1990; Retzinger and Mallory-Smith 1997). Using postemergence herbicides with different modes of action will enable producers to minimize development of resistant weed biotypes.

Knowledge of growth patterns of proso infesting corn will help producers plan effective control strategies. Therefore, this study was conducted to quantify ecological characteristics of proso infesting corn, define proso's critical period of interference, and suggest guidelines for controlling proso in corn with current postemergence herbicides.

MATERIALS AND METHODS

Site Description. Studies were conducted from 1990 to 1993 at Akron, CO. Long-term yearly precipitation is 419 mm, whereas average precipitation during the corn growing season (May through September) is 290 mm. Average air temperature during the growing season is 18.9 C and ranges from 13.5 C in May to 22.9 C in July. Soil was a Platner loam (Aridic Paleustoll) and cropping history of the site was winter wheat–proso millet–fallow. Each year the study site was established in proso residue with volunteer proso being the predominant weed.

Corn Production Practices. 'Pioneer 3732' corn was planted at 37,000 seeds/ha during the first week of May into a no-till seedbed. Row spacing was 75 cm. Ammonium nitrate was applied broadcast at 67 kg N/ha on the day of planting. Dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.3 kg ai/ha was applied in early June to control existing broadleaf weeds. Corn grain yield was standardized to 15.5% moisture content.

Proso Seedling Emergence Study. In 1990, 1991, and 1992, proso seedling emergence in eight 1-m^2 permanent quadrats in corn was recorded weekly, starting on May 4 and continuing until October. After counting, seedlings were pulled and removed. Total seedlings per year ranged from 250 to 1,200/m^2. The source of weed seeds was the indigenous soil seedbank. Other weeds emerging in quadrats were removed weekly.

Emergence pattern for each year was developed by converting seedling emergence per week into a percentage of total emergence over the growing season for all replications. Data over 3 yr were then averaged by weekly intervals with one standard deviation derived from yearly averages for each week.

Proso Development and Productivity Study. Seedlings were established in corn every 2 wk starting on May 18 and continuing for 10 wk in 1991 and 1992. To establish proso seedlings, seeds were planted in peat pellets[4] and incubated in a greenhouse until seedling emergence. Pellets containing seedlings were then transplanted 30 cm apart and equidistant between corn rows. There were eight replications with seedlings from each emergence date randomly mixed in each replication. Plot size was 0.8 by 1.5 m. Area surrounding the seedlings was maintained weed-free by hoeing.

Seedling development was characterized with the Zadoks-Chang-Konzak scale (Bauer et al. 1983). This scale assigns a number for each development stage, such as 20 for tillering and 30 for stem elongation, with the entire life cycle defined between 0 and 100. Development was measured until inflorescences emerged. Rate of development for the first three emergence dates was related to growing degree day (GDD) accumulation from seedling emergence. GDDs were calculated from daily air temperatures with the formula

$$\text{GDD} = (\text{Maximum temperature} + \text{minimum temperature}/2) - 10$$

using a base temperature of 10 C and a maximum of 30 C, the same temperature range used for corn (Aldrich et al. 1978).

Height of all proso seedlings in each planting date was measured weekly. Plants were harvested 2 wk before maturity to measure above-ground biomass, number of tillers, and seeds/plant. Early harvest prevented seed loss caused by shattering.

[4] American Clayworks and Supply Co., Denver, CO 80204.

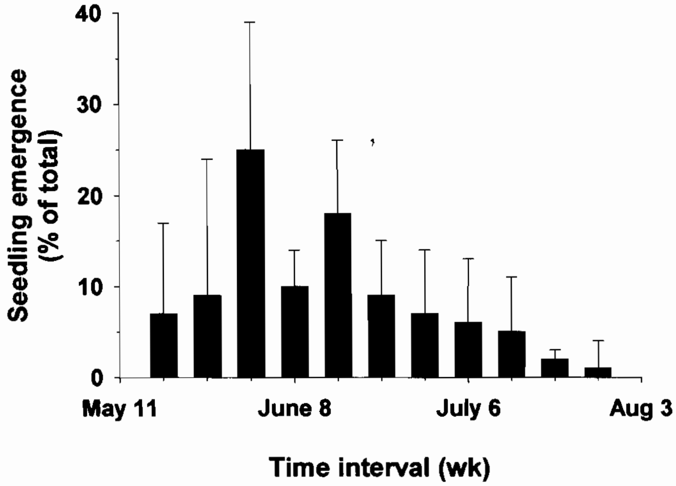

Figure 1. Weekly proso seedling emergence, averaged across 3 yr. Error bars represent one standard deviation.

Critical Period of Interference Study. In 1992 and 1993, plots were established to determine the effect of duration of proso interference on corn yield. Proso seedlings in corn were removed by hoeing 3, 4, 5, 6, or 7 wk after proso emergence with June 8 being the first removal date. Corn plants had two leaves on June 8 and eight leaves on July 6 (7-wk treatment). Weed-infested and weed-free controls also were established. Weeds were removed from the weed-free control treatment weekly by hoeing. Plot size was 4 by 8 m with eight replications. At corn tasseling, proso dry weight was measured in two 1-m^2 subsamples per plot. Proso density was approximately 125 plants/m^2. Corn yield was determined by hand-harvesting 15 m^2 of plot area.

Corn Planting Date and Height Study. Corn was planted every 7 d from April 29 to May 26 in 1991 and 1992. Plot size was 4 by 16 m with four replications. Volunteer proso was controlled by nicosulfuron applied in early and late June and by hoeing during the late season. Nicosulfuron was applied at 14 g/ha in 100 L/ha of spray solution. Five corn plants in each plot were marked and plant height was measured weekly starting with the two-leaf development stage. Grain yield was determined by hand-harvesting 30 m^2 of plot area.

Data Analyses. Experimental design for all studies except the seedling emergence study was a randomized complete block. Treatment means were analyzed by ANOVA and compared with Fisher's Protected LSD test at the 0.05 level of probability. Treatment-by-year interactions did not occur in any study; therefore, data were averaged across years.

Table 1. Proso millet productivity as affected by time of emergence. Data are averaged across 3 yr.

Date of emergence	Dry weight	Tillers	Seeds
	g/plant	Number/plant	
May 18	34.9	9.3	2,810
June 1	18.8	3.5	1,520
June 15	4.2	1.1	345
June 29	2.1	0.9	180
July 13	0.3	0.8	30
July 27	0.1	0.7	2
LSD (0.05)	3.6	0.3	300

RESULTS AND DISCUSSION

Proso Seedling Emergence. Volunteer proso emerged from May 18 to early August (Figure 1) with 78% of seasonal emergence occurring in a 6-wk period between May 18 and June 22. Highest emergence occurred on June 1. In one year, initial emergence was delayed until May 25 because of cool temperatures. The two emergence peaks on June 1 and June 15 reflect cyclic rainfall patterns.

Decision-aid models help producers select control strategies (Swinton and King 1994). These models evaluate ecological data of weeds, such as seedling emergence patterns, to predict long-term consequences of management options (Wiles et al. 1996). One goal of these models is to predict when seedling emergence begins. Roberts and Feast (1973) suggested that initial seedling emergence of weeds is governed by a temperature threshold so that when air temperatures reach a specific level, seedling emergence begins if moisture is available. Egley (1986) suggested that amplitude of daily temperature fluctuation most accurately described the temperature threshold for seedling emergence.

Using Egley's guidelines, we calculated daily air temperature fluctuation during the 7-d period before initial seedling emergence and averaged values across 3 yr. Proso began emerging when maximum and minimum daily temperatures were 22.1 ± 5.2 C (± standard deviation) and 6.2 ± 3.9 C, respectively. Average daily temperature was 14.1 ± 4.1 C.

Proso Development and Productivity Study. Grass development affects performance of graminicides, especially when plants begin tillering or stem elongates (Neal et al. 1990; Schreiber et al. 1979). To help producers and decision-aid models predict development, we related rate of proso development to GDD accumulation ($Y = 2.75 + 0.082X$; $r^2 = 0.91$; when $Y =$ development stage with the Zadoks-Chang-Konzak scale and $X =$ GDD since emergence). Proso seedlings

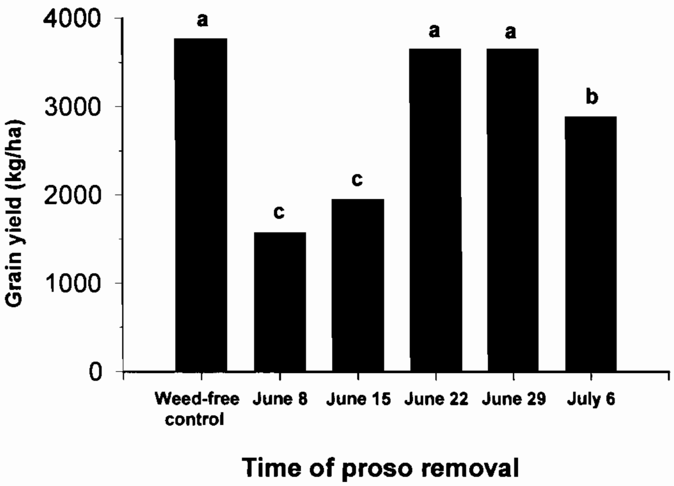

Figure 2. Effect of duration of proso interference on grain yield of corn. Data are averaged across 2 yr. Treatment means with identical letters do not differ as determined by Fisher's Protected LSD test at the 0.05 probability level.

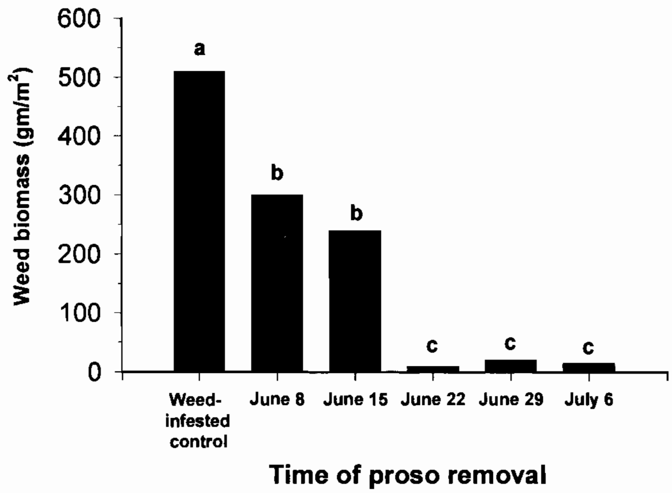

Figure 3. Biomass of proso at corn tasseling as affected by time of control. Data are averaged across 2 yr. Treatment means with identical letters do not differ as determined by Fisher's Protected LSD test at the 0.05 probability level.

began tillering after approximately 210 GDD and stem elongation began after 330 GDD. With average air temperatures, seedlings emerging in mid-May will initiate tillering by June 20.

Simulation models can predict impact of control strategies on long-term weed population dynamics if seed production per plant is known (Firbank and Watkinson 1986; Gonzalez-Andujar and Fernandez-Quintanilla 1991). For proso, seed production and plant growth were related to time of emergence (Table 1). When seedlings emerged on May 18, each plant produced on average 35 g of biomass and 2,810 seeds; in contrast, seedlings emerging on June 15 produced 88% less biomass and seeds/plant. Seed production per plant as related to time of seedling emergence was described by: $Y = 2{,}768 - 105X + 0.95X^2$ ($r^2 = 0.97$; X = days after May 18).

Critical Period of Interference. Corn grain yield was not reduced when proso was removed on June 22 or June 29, which corresponds to 5 or 6 wk of interference, respectively (Figure 2). In contrast, yield was reduced 48% when proso was removed on June 15. This yield loss was attributed to proso seedlings emerging after the removal treatment. Proso biomass at corn tasseling in this treatment was 240 g/m^2, approximately one-half of the biomass in the weed-infested control (Figure 3). The long interference period reduced corn yield when proso was removed on July 6 (Figure 2) because proso biomass in this treatment was similar to the June 22 and 29 treatments (Figure 3). However, yield loss was less with removal on July 6 compared with removing proso on June 8 or 15 (Figure 2). Full-season interference reduced corn yield 85% (data not shown).

Corn Planting Date and Height Study. Corn yield varies drastically in this semi-arid climate because of erratic precipitation during flowering (Anderson et al. 1999). To minimize this yield variability, producers plant corn over a 4-wk period in May to vary crop development. However, late-planted corn may prohibit use of some control options: post-directed applications of herbicides may injure corn plants that are not at least 40 cm tall and may not control proso taller than 15 cm (Fawcett and Harvey 1988).

Corn was taller than 40 cm by June 22 when planted on or before May 5 (data not shown). With later planting dates, however, corn was not tall enough to avoid crop injury. Corn planted on May 12 was only 30 cm tall on

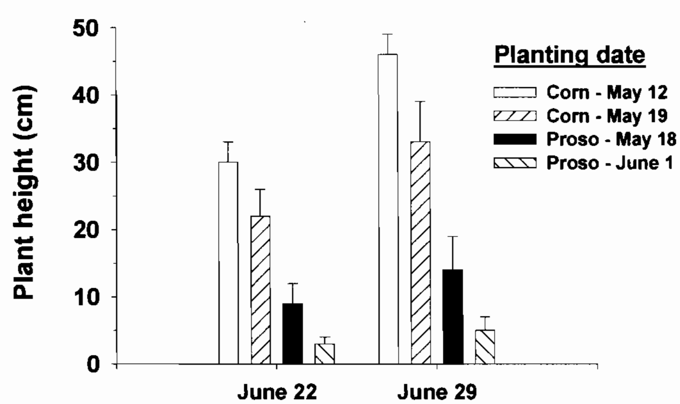

Figure 4. Plant height of corn and proso on June 22 and 29 as affected by planting date. Data are averaged across 2 yr. Error bars represent one standard deviation of the mean.

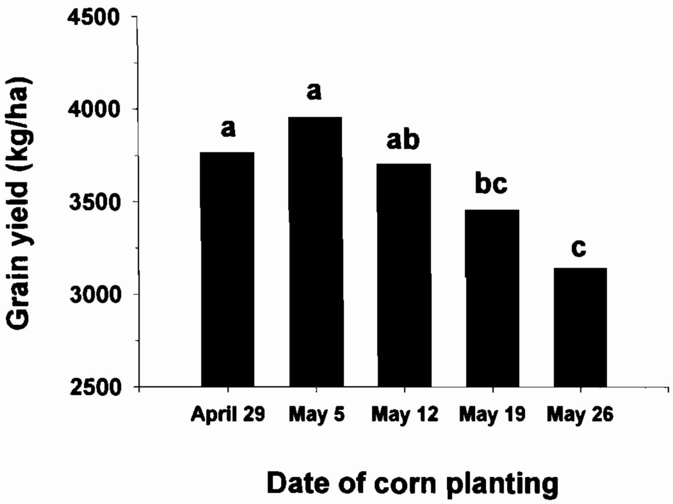

Figure 5. Corn yield as affected by planting date. Data are averaged across 2 yr. Treatment means with identical letters do not differ as determined by Fisher's Protected LSD test at the 0.05 probability level.

June 22, whereas corn planted May 19 was less than 25 cm tall (Figure 4). By June 29, only corn planted on May 12 exceeded 40 cm in height. Proso seedlings were less than 15 cm tall on both June 22 and June 29, regardless of emergence date (Figure 4). If producers vary planting dates to manage erratic precipitation, lack of sufficient corn height with later planting dates may preclude use of postemergence-directed technology.

Grain yield did not differ when corn was planted April 29, May 5, or May 12; yield was reduced 10 to 17% at later planting dates (Figure 5). Regressing yield loss with delay in planting for the May 5 to May 26 data showed that grain yield decreased approximately 40 kg/ha per day of delay after May 5.

Applications for Weed Management. By targeting control actions to occur between 4 and 5 wk of proso interference, producers can prevent yield loss in corn (Figure 2) and reduce seed production by later-emerging proso seedlings (Table 1), yet maintain maximum flexibility in herbicide options. For example, proso tolerance to nicosulfuron increases when plants are taller than 10 cm (Tapia et al. 1997); however, proso was less than 10 cm tall 5 wk after emergence (Figure 4). Graminicide effectiveness is reduced when grasses are tillering (Neal et al. 1990), yet with normal air temperatures for this location, proso seedlings will not start tillering until after 5 wk of growth. Thus the 5-wk interference window favors control options with graminicides. Herbicides such as paraquat applied with postemergence-directed technology also are an option because corn will be 40 cm tall at time of application if planted by early May (Figure 4).

Rotating herbicides with different modes of action will help producers minimize selection pressure for herbicide-resistant weeds (Retzinger and Mallory-Smith 1997). Because mode of action differs among nicosulfuron, paraquat, glyphosate, and sethoxydim, producers have multiple options to not only control grasses in corn, but also minimize selection pressure for weed resistance.

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