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A Cultural System Approach Can Eliminate Herbicide Need in Semiarid Proso Millet (*Panicum miliaceum*)[1]

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Abstract: Producers in the semiarid Great Plains are seeking management strategies to delay development of herbicide resistance. The objective of this study was to determine if cultural systems could control weeds in proso millet (*Panicum miliaceum*), thus eliminating the need for herbicides and removing selection pressure. Initially, we evaluated individual cultural practices for improving competitiveness of proso millet. Increasing seeding rate, banding N fertilizer with the seeds, growing a taller cultivar, and eliminating tillage favored proso millet over redroot pigweed (*Amaranthus retroflexus*). Combining several cultural practices with delayed planting in a cultural system reduced biomass and seed production of two pigweed species 85% or more in both tilled and no-till systems, subsequently eliminating proso millet yield loss. Density of the two pigweed species was sevenfold greater in the tilled system, yet the cultural system approach was still effective. Cultural system impact on seed production suggests that pigweed densities will not increase over time. With cultural systems, producers can minimize selection pressure, thus delaying development of herbicide resistance.

Nomenclature: Redroot pigweed, *Amaranthus retroflexus* L. #[3] AMARE; proso millet, *Panicum miliaceum* L. 'Cope', 'Sunup'.

Additional index words: Delayed planting, increased seeding rate, nitrogen placement, tillage, AMARE.

INTRODUCTION

Producers in the semiarid Great Plains are changing their crop rotations because of the advantages of no-till production systems. No-till systems are especially favorable in this region because herbicides replace tillage, which leaves more crop residue on the soil surface. Crop residue increases both precipitation storage in soil and water use efficiency of crops (Peterson et al. 1996); consequently, producers are growing corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.), and proso millet (*Panicum miliaceum*) in rotation with winter wheat (*Triticum aestivum* L.).

An alarming concern, however, is the increase in weeds resistant to herbicides. For example, atrazine has been used for weed control during noncrop periods, resulting in resistant biotypes of downy brome (*Bromus tectorum* L.), witchgrass (*Panicum capillare* L.), and redroot pigweed (*Amaranthus retroflexus*) (Holt and LeBaron 1990). Also, sulfonylurea herbicides are used in several crops grown in this region, including proso millet; two especially troublesome weeds, kochia [*Kochia scoparia* (L.) Schrad.] and Russian thistle (*Salsola iberica* Sennen and Pau), are now resistant to these herbicides (Lyon et al. 1996).

Producers can reduce selection pressure on weed populations by minimizing use of long-residual herbicides (Holt and LeBaron 1990) and rotating herbicides with different modes of action (Gressel and Segel 1990). However, proso millet, because of its small hectarage, has few herbicides registered for crop use; thus, management options based on herbicide diversity are limited. Producers can replace herbicides with tillage (Holt and LeBaron 1990), but this option has negative consequences in the Great Plains: each tillage operation buries surface crop residue, thereby reducing water use efficiency of semiarid crops (Peterson et al. 1996). Furthermore, tillage increases seedling emergence of some weed species (Egley 1986; Froud-Williams et al. 1984).

Another option is to strengthen a crop's competitiveness to weeds with cultural practices (Lewis et al. 1997). For example, green foxtail [*Setaria viridis* (L.) Beauv.] density is reduced in barley (*Hordeum vulgare* L.) when N fertilizer is banded with the crop seeds compared with

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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.

a broadcast application (O'Donovan et al. 1997), whereas downy brome interference in winter wheat is minimized by growing taller cultivars (Challaiah et al. 1986). Other cultural practices that favor crops over weeds include narrow rows, delayed planting, and higher seeding rates (Anderson 1997; Koscelny et al. 1991).

A common approach to minimize selection pressure is combining one or two cultural practices with reduced herbicide rates (Mickelson and Renner 1997). Various aspects of semiarid proso millet production, however, suggest that weeds possibly can be controlled by cultural practices without herbicides. First, proso millet is usually planted after the majority of weed seedlings have emerged in northeastern Colorado (Anderson 1994a, 1994b). Second, precipitation is erratic in this region, resulting in extensive dry periods with minimal weed seedling emergence. A further aspect favoring a cultural approach in proso millet is the additive or synergistic effect of combining individual cultural practices into cultural systems; a crop's competitiveness to weeds can be increased four- to sixfold in a cultural system compared with a single cultural practice (Anderson 1997).

We hypothesized that the interaction between weed emergence patterns, erratic precipitation, and synergism of cultural systems would enable producers to control weeds in proso millet without herbicides. Therefore, the objectives of this study were to first evaluate individual cultural practices in proso millet for the effect on weed growth, then guided by these results, compare cultural systems comprised of the most favorable practices for minimizing weed interference. Our goal was to develop cultural weed control systems that would allow producers to eliminate herbicide selection pressure in proso millet, thereby favoring susceptible biotypes in weed populations and delaying development of resistant populations (Roush et al. 1990).

MATERIALS AND METHODS

Site Description and General Procedures. The study was conducted from 1995 through 1999 at Akron, CO. Long-term yearly precipitation is 419 mm, whereas average precipitation during the proso millet growing season (June through August) is 184 mm. Average air temperature during the growing season is 21.1 C. In all years, study sites were established in winter wheat stubble on a Weld silt loam (Aridic Paleustoll).

Unless stated otherwise, studies were established in a no-till system. Proso millet was planted with a low-disturbance drill with double-disk openers. Row spacing was 20 cm. Nitrogen fertilizer formulation for all studies was ammonium nitrate. Proso millet was harvested for grain yield by swathing when the top two-thirds of the head had turned white, followed by combining 7 to 10 d later. Harvest occurred in early September of each year. Grain yield was standardized to 10% moisture.

Redroot pigweed was the predominant species in the indigenous seed bank. To minimize spatial variability in plots, redroot pigweed seeds (200 seeds/m^2) were broadcast on the soil surface the previous fall of each year.

Effect of Proso Millet Seeding Rate and Cultivar on Weed Growth. In 1995 and 1996, two proso millet cultivars, Sunup (short stature, mid-maturity) and Cope (tall stature, late maturity), were seeded at 11 and 17 kg/ha, respectively. Plots were planted in early June of each year, with N fertilizer applied broadcast at 40 kg N/ha 1 d before planting. Plot size was 3 by 8 m.

At proso millet harvest, 10 random redroot pigweed plants in each plot were harvested to determined fresh weight; redroot pigweed density ranged from 3 to 5 plants/m^2. Number of proso millet culms per 1 m of row were counted at six sites per plot. Height from the soil surface to the top of the undisturbed plant was measured on six random plants. Grain yield was determined from an area 1.5 by 7 m.

Effect of Nitrogen Management on Weed Growth in Proso Millet. Treatments comprised of timing and methods of N application were evaluated for effect on weed growth. Nitrogen fertilizer was applied in either early April or 1 d before planting in June, whereas two methods of N application were compared at each date: broadcast vs. broadcast plus banding. Nitrogen was applied at 40 kg N/ha for both methods; however, with broadcast plus banding, 5 kg N/ha of the total was applied with the seeds at planting. A prevalent fertilizer practice used by producers is broadcasting 40 kg N/ha before planting. A control treatment of no fertilizer was included for comparison.

Sunup was planted at 11 kg/ha in early June of 1995 and 1996. Prior to proso millet harvest, fresh weight of redroot pigweed and proso millet was determined from two 1-m^2 quadrats randomly located in each plot. Redroot pigweed density was approximately 5 to 8 plants/m^2. Community composition was determined by dividing fresh weight of redroot pigweed by fresh weight of redroot pigweed plus proso millet in each quadrat. Plot size was 4 by 8 m, and proso millet grain yield was determined from an area 1.5 by 7 m.

Effect of Tillage on Weed Emergence in Proso Millet. Three levels of tillage before planting were compared: 0

(no-till), 1, or 2 tillage operations. In the no-till treatment, weeds were controlled after wheat harvest until proso millet planting by repeat applications of glyphosate at 0.4 kg ae/ha as needed. With the tilled treatments, tillage with the sweep plow[4] in April or May substituted for either one or two glyphosate applications to control weeds before planting.

Sunup was planted at 11 kg/ha in early June 1995 and 1996. Nitrogen fertilizer at 40 kg N/ha was applied broadcast 1 d before planting. Plot size was 9 by 9 m. Redroot pigweed seedling emergence was recorded weekly in four 0.25-m^2 permanent quadrats, randomly located in each plot. The first observation started on June 5 and continued until August 1. Seedlings were pulled and removed after counting. At proso millet harvest, redroot pigweed density was recorded in two 1-m^2 quadrats, randomly located in each plot. Proso millet grain yield was determined from an area 3 by 8 m.

Cultural Systems for Weed Control in Proso Millet. Guided by results from our individual cultural practice studies, we devised two cultural systems to compare with the prevalent production system used by producers. Because proso millet is commonly grown with either a no-till or a minimum-till approach, we compared these systems in both tillage methods. Producers plant Sunup at 11 kg/ha and apply N at 40 kg/ha broadcast 1 d before planting (hereafter referred to as the producer system). One cultural system was comprised of Cope planted at 17 kg/ha, with N fertilizer split between broadcast (35 kg N/ha) application 1 d before planting and banding with the seeds (5 kg N/ha). With the second cultural system, Sunup replaced Cope and planting was delayed 2 wk in minimum-till and 1 wk in no-till. The target planting date for the minimum-till method (May 28) was 2 wk earlier than for no-till (June 10), to correspond with the optimal planting date for each tillage method (Anderson 1994a).

The study was conducted in 1997, 1998, and 1999, with plots established at different sites each year. Weeds present after wheat harvest and before proso millet planting were controlled by repeat applications of glyphosate in the no-till system and one application of glyphosate after wheat harvest followed by two sweep plow operations in April and May in the minimum-till method. Plot size was 10 by 10 m. Each plot was split into weed-free (weeds removed by hand) and weed-infested subplots. Redroot pigweed seeds were broadcast only on the weed-infested subplots. Tumble pigweed (*Amaranthus albus* L. # AMAAL) also was observed in this study, comprising approximately 30% of the weed community.

Pigweed (data of both species were combined because of difficulty in distinguishing between seedlings) densities were recorded 4 wk after emergence in two permanently-marked 1-m^2 quadrats per weed-infested plot. Pigweed was harvested from each quadrat immediately before swathing proso millet, to determine fresh weight. After air-drying for 3 wk, pigweed samples from each quadrat were processed to determine seed production. After hand-threshing, seed number was determined from a subsample, which was 1/20th of the weight of each quadrat's seed sample. Proso millet grain yield was determined from an area 5 by 5 m for both weed-free and weed-infested subplots within each plot.

Experimental Design and Data Analyses. For all studies, plots were arranged in a randomized complete block design with four replications. The seeding rate and cultivar study and cultural system study were analyzed as a factorial. If subsamples were collected within a plot, subsample values were averaged for a plot mean. Data were analyzed by ANOVA and means were compared with Fisher's protected LSD at the 0.05 level of probability. If treatment by year interactions did not occur, data were averaged across years.

RESULTS AND DISCUSSION

Effect of Proso Millet Seeding Rate and Cultivar on Weed Growth. Increasing the seeding rate of Sunup to 17 kg/ha reduced redroot pigweed biomass 25% (Figure 1). The competitiveness of proso millet was further enhanced by planting Cope, a taller cultivar, at 17 kg/ha; redroot pigweed biomass was almost 60% less compared to Sunup planted at 11 kg/ha. Research with other crops has shown that taller cultivars (Challaiah et al. 1986) and higher plant density (Anderson 1997) improve a crop's competitiveness to weeds. In our study, higher seeding rates increased proso millet plant density 25% (data not shown), and Cope was approximately 15 cm taller than Sunup (data not shown); thus, these two factors improved the crop's competitiveness. Proso millet grain yield did not differ among treatments (Figure 1); therefore, producers have flexibility with seeding rates and cultivars in designing cultural systems.

Effect of Nitrogen Management on Weed Growth in Proso Millet. All N treatments increased redroot pigweed biomass compared with the control (Table 1). Proso millet responded most favorably to treatments that included N banding with the seed at planting: both bio-

[4] The sweep plow consists of V-shaped blades, 76 cm wide, that sever weed roots with minimum soil disturbance, tilling to a depth of 5 to 8 cm.

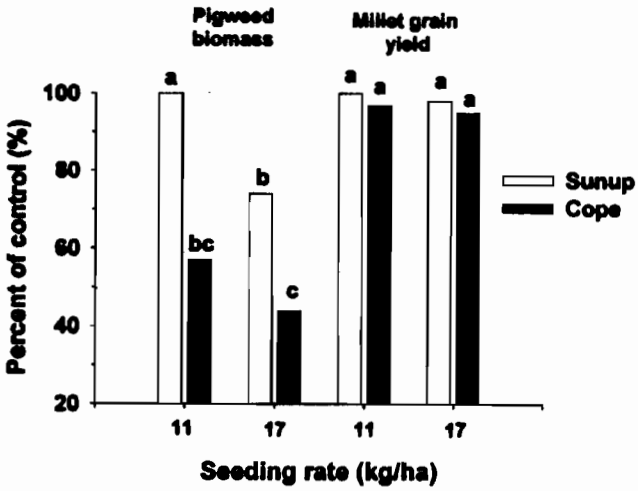

Figure 1. Effect of proso millet seeding rate and cultivar on biomass of redroot pigweed and grain yield of proso millet, compared with the control treatment of Sunup planted at 11 kg/ha. Data were averaged across 2 yr. Treatment means with identical letters do not differ significantly based on Fisher's protected LSD (0.05). Redroot pigweed biomass (fresh weight) was 6.2 g/plant, and grain yield was 1,880 kg/ha for the Sunup planted at 11 kg/ha treatment.

mass and grain yield were increased at least 30% compared to the control. In contrast, broadcasting N without banding in either April or June did not improve proso millet grain yield.

Timing of application also affected weed growth. With the broadcast plus banding treatments, applying the broadcast component of N in April increased redroot pigweed biomass 25% compared with the June application (Table 1). Also, broadcasting N in April increased the redroot pigweed component of the plant community compared with the control treatment (Table 1). We attribute this response to differences in rooting patterns: redroot pigweed has a taproot, in contrast to the fibrous root system of proso millet. Nitrogen applied in April may have leached into the soil profile; the tap root of redroot pigweed enabled it to access N earlier than proso millet. Based on trends with proso millet yields and redroot pigweed biomass, the most favorable N application method for proso millet competitiveness was broadcast plus banding, with the broadcast component of N applied in June.

Effect of Tillage on Weed Emergence in Proso Millet. Tilling before planting increased redroot pigweed seedling emergence 58% compared with the no-till treatment (Table 2). Similar trends occurred with redroot pigweed density at proso millet harvest; tillage increased density 35% compared with no-till. Number of tillage operations did not affect redroot pigweed emergence or density at proso millet harvest. Two factors may have contributed to increased seedling emergence of redroot pigweed: (1) shallow tillage placed the seeds in soil, which increases emergence compared to no-till (Ogg and Dawson 1984), and (2) there is more crop residue on the soil surface of no-till, which reduces emergence (Anderson 1999).

Proso millet yielded 10% more in no-till than in either minimum-till treatments (Table 2), which probably occurred because of improved water relations (Anderson 1990) and less weed interference. To minimize herbicide use and selection pressure, producers may till to control weeds before planting proso millet. However, our results indicate that tillage favors redroot pigweed emergence; thus, tillage may necessitate other control options in proso millet.

Cultural Systems for Weed Control in Proso Millet. A tillage by cultural system interaction occurred. Because tillage means also differed, we analyzed cultural systems within tillage treatments. One possible cause of the tillage by cultural system interaction was the sevenfold difference in pigweed density between the minimum-till and no-till methods (Table 3).

With the minimum-till method, cultural system 3, comprised of a higher seeding rate, N banding, and de-

Table 1. Nitrogen application effect on growth of redroot pigweed and proso millet.

Nitrogen application	Redroot pigweed		Proso millet[a]	
	Biomass	Community component	Biomass	Grain yield
	g/m²	%		
April	165	13	106	107
April + banding	203	13	133	134
June	146	10	122	107
June + banding	153	12	140	144
Control (0 N)	83	7	100	100
LSD (0.05)	40	5	16	13

[a] Control mean for proso millet biomass (fresh weight) was 1,200 g/m² and grain yield was 1,450 kg/ha.

Table 2. Seedling emergence and harvest density of redroot pigweed, and proso millet yield as affected by tillage treatment.

Tillage treatment[a]	Redroot pigweed		Proso millet grain yield
	Seedling emergence	Density at proso millet harvest	
	plants/m²		kg/ha
Sweep plow once	73	27	1,710
Sweep plow twice	70	32	1,780
No-till	45	20	1,980
LSD (0.05)	19	6	100

[a] Glyphosate as needed until spring then tillage with the sweep plow replaced one or two applications of glyphosate.

Table 3. Cultural systems effect on weed growth and interference in proso millet, 1997–1999.

Cultural system within tillage method				Pigweed complex			Weed-infested proso millet yield loss
Variety	Seeding rate	N placement[a]	Planting date	Density	Fresh weight biomass	Seed production	
	kg/ha			planta/m²	g/m²	seeds/m²	%
Minimum-till							
1. Sunup	11	Broadcast	May 28	42	475	88,400	29
2. Cope	17	Band	May 28	39	215	27,900	9
3. Sunup	17	Band	June 10	8	56	8,100	2
LSD (0.05)				16	114	20,500	6
No-till							
4. Sunup	11	Broadcast	June 10	6	72	9,700	4
5. Cope	17	Band	June 10	5	41	5,600	2
6. Sunup	17	Band	June 17	1	7	600	0
LSD (0.05)				2	32	4,600	2

[a] Band refers to N being applied broadcast at 35 kg/ha plus banded at 5 kg/ha with the seed at planting.

layed planting, reduced pigweed density, growth, and seed production 80% or more compared with the producer system (system 1 in Table 3). Because of reduced pigweed growth, yield loss in system 3 was 15-fold less than in the producer system (2% compared to 29%). The cultural system with Cope (system 2) reduced pigweed biomass 55% and seed production 69% compared with system 1, even though pigweed densities were similar. Millet yield loss due to pigweed interference was 20% less with the Cope system than with system 1.

With no-till, the only difference with pigweed growth among cultural systems occurred when planting was delayed (compare systems 4 and 5 with system 6 in Table 3). For example, pigweed biomass and seed production were reduced at least 90% in system 6 compared to the producer system (system 4), whereas pigweed growth did not differ between system 4 and the cultural system with Cope. Yield loss due to pigweed interference was minimal (4% or less) in all no-till systems, contrasting with the 29% yield loss with the producer system in minimum-till (system 1 in Table 3). This contrast in yield loss reflects the sevenfold difference in pigweed densities between the tillage methods.

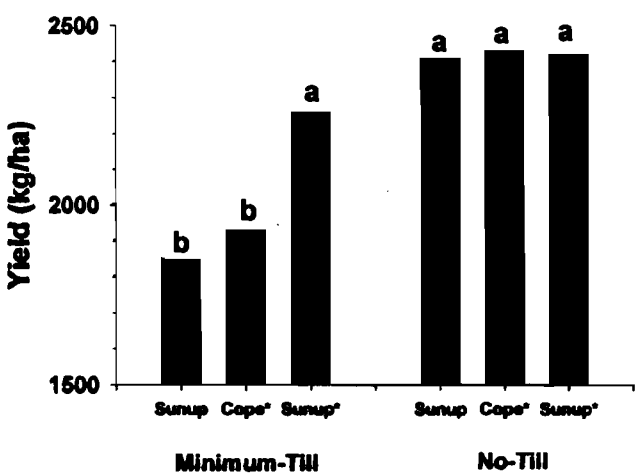

Figure 2. Grain yield of proso millet in weed-free conditions as affected by cultural systems. A cultural system by tillage method interaction occurred; therefore, data were analyzed within tillage methods. Data were averaged across 3 yr. Treatment means within a tillage method with identical letters do not differ significantly based on Fisher's protected LSD (0.05). Cope* and Sunup* are cultural systems comprised of various cultural practices; see Table 3 for the system's cultural components.

Delaying proso millet planting reduced pigweed densities in both tillage methods (Table 3). Redroot pigweed begins emerging in late May and early June in this region, with tillage increasing the magnitude of emergence but not changing the pattern of emergence (Anderson and Nielsen 1996). With later planting of proso millet, tillage in the minimum-till method and glyphosate in the no-till method eliminated pigweed seedlings present at planting time, thus reducing densities compared to treatments planted earlier.

Proso millet grain yield in weed-free conditions did not differ among the three systems in no-till. In contrast, yields among systems in the minimum-till method differed by 23%; the cultural system with Sunup yielded approximately 400 kg/ha more than the producer system (Figure 2). Yields of Sunup in the producer systems of each tillage method (systems 1 and 4 in Table 3) differed by 30% (Figure 2), which agrees with previous research that showed a similar yield advantage when growing proso millet with no-till (Anderson 1990).

Applications for Weed Management. A basic component of any strategy to manage weed resistance is to minimize selection pressure. Current strategies include rotating herbicides with different modes of action, substituting tillage for herbicides, and supplementing re-

duced rates with cultural practices (Gressel and Segel 1990; Holt and LeBaron 1990). Cultural systems offer producers another strategy, as weeds can be controlled and yield loss avoided in proso millet without using herbicides. This cultural approach eliminates selection pressure in one year of the rotation, thus favoring populations of susceptible biotypes, which subsequently delays development of resistance (Roush et al. 1990).

Producers also will accrue ancillary benefits with a cultural systems approach. First, weed densities infesting millet are extremely variable within the field, with areas of no weeds. Second, proso millet can be injured by postemergence herbicides in some years, especially in dry conditions, with yield losses approaching 20% (Lyon and Miller 1999). Thus, the cultural approach avoids unnecessary herbicide input and possible yield loss due to herbicide injury. A further benefit of cultural systems is that improved competitiveness of proso millet will enhance efficacy if herbicides are used to control weeds in-crop.

A concern with cultural-based weed control is that seed production of weeds present in proso millet will lead to higher weed densities in following crops. Population dynamics studies have shown that weed populations in rotations remain relatively stable or decline if control efficacy is approximately 85 to 90%, based on weed densities (Cousens 1986; Gonzalez-Andujar and Fernandez-Quintanilla 1991) or weed biomass (Bosnic and Swanton 1997). In our study, the most effective cultural system in either tillage method achieved these control levels with both pigweed biomass and seed production (Table 3). Our results suggest that cultural efficacy in both tillage methods may be sufficient to avoid pigweed population growth over time. An intriguing finding was that pigweed seed production among systems varied almost 150-fold (compare systems 1 and 6, Table 3), demonstrating the magnitude at which cultural choices in proso millet can affect weed seed production.

Producers in this region can further counter weed population growth by crop sequencing. For example, semiarid rotations can be designed to favor weed seedbank decline. If proso millet is followed by two winter crops or a winter crop and fallow, seedbank density of summer annual weeds can decline nearly 90% (Anderson 1998).

Heap (1997) suggested that resistance management can be improved by integrating a multiple of control options into a complex weed management system that includes crop sequencing options. Our study indicates that cultural systems are a viable option for producers to replace herbicide use in proso millet. Integrating cultural systems with rotation design will further strengthen producer options in managing weed populations that are resistant to herbicides.

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