\# 170

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Effect of Tillage Systems on Proso Millet Production[1]

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ABSTRACT

Proso millet (*Panicum miliaceum* L.) is well-adapted for the Central Great Plains and could be planted in a winter wheat (*Triticum aestivum* L.)–millet–fallow rotation, resulting in two crops in 3 yr. To determine the most suitable tillage system for proso millet production within this rotation, seven tillage management systems were evaluated over a 6-yr period (1972–1977). The research was conducted on a mesic Pachic Arguistill soil on the Central Great Plains Research Station near Akron, CO. Comparisons included fall vs. spring tillage and replacing a tillage operation with herbicides. Controlling fall weed growth by tillage alone or with atrazine (2-chloro-4-ethylamino-6-isopropylamino-*S*-triazine) increased grain yield of proso millet and protein content of the grain more than spring tillage for weed control. Increased millet production from fall tillage was attributed to increased soil NO_3^--N levels and increased soil water use by millet. Water use efficiency by millet was also increased with fall tillage. Adding N fertilizer decreased millet grain production.

***Additional index words:* *Panicum miliaceum* L., Nitrogen, Atrazine, Water use efficiency, Grain protein.**

THE DEVELOPMENT of more efficient cultural practices for storing soil water during fallow periods would increase the potential of producers to grow two crops in 3 yr in the Central Great Plains, rather than one crop in 2 yr. One possible two-crop in 3-yr scheme could be proso millet (*Panicum miliaceum* L.) planted after winter wheat (*Triticum aestivum* L.), resulting in a wheat–millet–fallow rotation. Proso millet is well-adapted for the Great Plains, being a short-season crop with a low water requirement (Briggs and Shantz, 1913). Maximum water demand during the growing season for proso millet in the Central Great Plains is 300 to 350 mm compared with 500 to 550 mm for corn (*Zea mays* L.) or grain sorghum (*Sorghum bicolor* L. Moench) (Greb, 1979).

Management systems in wheat–fallow rotations affect soil water and NO_3^--N levels. Wicks and Smika (1973) reported that half of the total weed growth in a tillage system for fallow occurred in the fall after wheat harvest. The fall weed growth can use up to 76 mm of stored soil water (Good and Smika, 1978). Thus, control of fall weeds would increase soil water storage. Greb and Zimdahl (1980) reported that decreased tillage during the fallow season increased soil NO_3^--N levels (weeds being controlled by herbicides). Greb et al. (1974) reported that uncontrolled fall weed growth can consume up to 36 kg/ha of available N. Fallow programs, in which fall weed growth was controlled, increased the protein content of winter wheat grain.

Researchers have evaluated spring tillage systems for proso millet production. Nelson and Fenster (1983) compared four methods of preparing a seedbed (burn, plow, stubble mulch, and no-till) in combination with three types of planting on proso millet production. Their results indicated that neither the seedbed nor planter influenced proso millet grain yield. Fertilizer requirements within different tillage systems for proso millet have not been determined. Hinze (1977) speculated that proso millet might respond to N fertilizer if planted into wheat stubble, but not when grown on summer-fallowed land of medium to heavy texture.

To determine the optimal proso millet production system, this experiment was conducted (i) to evaluate the effect of tillage systems in wheat stubble on fall weed growth, soil water storage, soil NO_3^--N level, and proso millet production, and (ii) to determine N fertilizer influence on proso millet production following wheat in different tillage systems.

MATERIALS AND METHODS

The effects of tillage systems on proso millet production were evaluated in five cropping sequences from 1972 to 1977. The experiment was conducted on a Rago silt loam (fine, montmorillonitic, mesic Pachic Argiustoll) at Akron, CO. The soil contained 13 g/kg organic matter and the pH was 7.4. The experimental design was a randomized complete block with five treatments replicated four times. Plot size was 10 m wide by 24 m long, being established in wheat stubble each year.

The treatments evaluated over the duration of the study are shown in Table 1. Tillage system no. 1, spring disking, represents the normal production scheme followed in the Central Great Plains. Disking was performed with a 4-m

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tandem disk, while a V-blade was used for sweep plowing. Herbicides were applied at 2.8×10^4 kg/m² in 187 L/ha of spray solution with a 4-m boom plot sprayer. The general dates for each cultural operation during the study are shown in Table 1. 'Leonard' proso millet was planted with a deep-furrow drill at 7.2 kg/ha in 0.3-m rows in early June of each year and harvested in early September. The environmental data over the duration of this study is shown in Table 2. Precipitation levels for the five cropping periods ranged from 61 to 133% of the 75-yr average.

Table 1. Description of tillage system treatments.

Tillage system	Cultural operations	Tested in cropping sequence†
1	Spring disk twice (early April and early May), mulch-tread, and plant millet (early June)	1,2,3,4,5
2	Spring sweep plow twice (early April and early May), mulch-tread, and plant millet (early June)	1,2
3	Fall sweep plow once (July), spring sweep plow (early May), mulch-tread, and plant millet (early June)	3,4,5
4	Fall sweep plow twice (July and September), mulch-tread, and plant millet (early June)	1,2,3,4,5
5	Fall sweep plow once, atrazine at 0.56 kg/ha (July), mulch-tread, and plant millet (early June)	4,5
6	Fall sweep plow once, atrazine at 1.12 kg/ha (July), mulch-tread, and plant millet (early June)	1,2,3,4,5
7	Fall sweep plow once, 2,4-D butyl-ester at 2.24 kg/ha (July) mulch-tread, and plant millet (early June)	1,2

† Cropping sequence refers to the time period between after wheat harvest operations to proso millet harvest, occurring in two cropping seasons. Cropping sequence 1: 1972–1973; 2: 1973–1974; 3: 1974–1975; 4: 1975–1975; and 5: 1976–1977.

Table 2. Environmental data for the five cropping sequences, 1972–1977, and the 75-yr averages.

Cropping years	Fallow period precip.	Soil water storage†	Growing season precip.	Avg monthly temperatures for growing season of millet: June	July	Aug.
	mm			°C		
1972–1973	502	315	163	18.9	21.7	23.3
1973–1974	268	160	151	20.0	24.4	20.0
1974–1975	254	137	233	17.8	22.8	22.8
1975–1976	157	145	149	18.9	23.9	21.7
1976–1977	296	165	114	21.7	23.9	21.7
75-yr avg	320	–	180	19.4	22.8	22.2

† Average of all treatments within that year.

Table 3. Effect of tillage system on fall weed growth, soil water storage, and soil nitrate levels at planting in the 1972–1973 and 1973–1974 cropping sequences.

Tillage system	Fall weed growth	Fall water storage	Total water storage	Soil nitrate level at planting
	kg/ha	mm	mm	kg/ha
1. Spring disk twice	1310	12	165	55
2. Spring sweep plow twice	1410	14	162	53
4. Fall sweep plow twice	310	30	172	81
6. Fall sweep plow once, + atrazine at 1.12 kg/ha	330	34	173	69
7. Fall sweep plow once, + 2,4-D ester at 2.24 kg/ha	810	40	172	58
CV (%)	14.6	23.4	7.6	12.9
Single degree of freedom contrasts (*F* values)				
1 + 2 vs. 4 + 6 + 7	231.40**	39.10**	2.54	18.01**
4 vs. 6 + 7	11.04**	2.78	0.01	11.98**
6 vs. 7	28.30**	1.00	0.01	3.03
1 vs. 2	1.26	0.14	0.26	0.34

** Significant at the 0.01 probability level.

Fall weed growth was harvested from two 1-m² quadrants, oven-dried at 60°C, then weighed. Soil water content was determined gravimetrically on four dates: (i) after wheat harvest; (ii) at fall dormancy after tillage operation (late October); (iii) at millet planting; and (iv) after millet harvest. Samples were taken at 0.3-m increments to a depth of 1.2 m, with two samples per plot. Soil NO_3^--N levels were determined with the Kjeldahl method (Bremner, 1965) from samples taken at millet planting. Two samples per plot were collected at depths of 0 to 0.3 m and 0.3 to 0.9 m. Plant samples were hand harvested from 12 rows 1.2 m long to determine grain and straw yields. Grain protein content was determined by the Kjeldahl method (Bremner, 1965).

In 1974 and 1975, N (ammonium nitrate) was broadcasted by hand at 0 and 42 kg/ha over the tillage treatments in a split-plot arrangement to evaluate N effects on proso millet production. The 0 level treatment was included in the tillage systems comparisons, as well as in the N fertilizer comparison. Grain and straw yields and grain protein were determined as outlined above.

Analyses of variances (ANOVA's) were made for within and among years for the tillage system treatments, and single degree of freedom contrasts were used to separate mean differences among treatments (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Cropping Sequence Comparisons: 1972–1973 and 1973–1974

In comparison with the spring tillage systems (1 and 2), the three fall tillage systems (4, 6, 7) reduced the fall weed growth of redroot pigweed (*Amaranthus retroflexus* L.), kochia (*Kochia scoparia* L.), and volunteer winter wheat in 1972 and 1973 (Table 3). This suppression of fall weed growth more than doubled fall soil water storage. However, by millet planting time, total soil water storage was the same for all tillage systems. Sweep plowing twice in the fall (system 4) or fall sweep plowing once + atrazine (2-chloro-4-ethylamino-6-isopropylamino-*S*-triazine) fall applied (system 6) significantly increased soil NO_3^--N compared with the spring tillage systems (1 and 2). This increase resulted from the fall weed suppression as Greb and Zimdahl (1980) and Greb et al. (1974) reported that uncontrolled weed growth reduces soil NO_3^--N accumulation in fallow in the Central Great Plains. The increased weed biomass in the tillage system with 2,4-D[(2,4-dichlorophenoxy) acetic acid] resulted from lack of residual herbicide activity to suppress late fall weed growth. Atrazine or the second sweep plow operation in tillage system 4 and 6 removed this weed growth.

The effect of tillage system on millet grain yield for the first two cropping sequences is shown in Table 4. The tillage systems with fall operations (systems 4, 6, and 7) resulted in increased grain yield, which is explained by increased soil water use during the cropping season and increased levels of soil NO_3^--N (Tables 3 and 4). One possible explanation for increased soil water use by the fall tillage system even though stored soil water did not differ (Table 3), may be a difference in water distribution of the soil profile. Tilling in the spring would have dried out the upper 10 to 15 cm of soil in tillage systems 1 and 2, which may have reduced millet seedling vigor. Reduced seedling vigor in the spring-tilled treatments might have resulted in less millet root penetration over the growing season compared to millet growing in the more moist fall tilled soil. Also, increased N levels increase the extent of a plant's root system (Tisdale and Nelson, 1971). Fall tillage systems had higher soil NO_3^--N levels, which would have increased millet root growth. This smaller root system of the less vigorous millet plant in the spring tillage system would decrease water uptake later in the growing season.

Tillage system did not affect harvest index but grain protein content was increased with fall tillage (Table 4). This increase in protein content reflected the tillage system effect on soil NO_3^--N levels.

Cropping Sequence Comparisons: 1975–1976 and 1976–1977.

Two new tillage systems were added in the 1975–1976 cropping sequences: sweep plowing in both the fall and spring (tillage system 3), and sweep plowing once in the fall with atrazine applied at 0.56 kg/ha (tillage system 5). Atrazine at both rates applied after sweep plowing following winter wheat harvest (tillage systems 5 and 6) resulted in grain yield increases compared to the completely mechanical tillage systems (Table 5). This yield increase resulted from a combination of increased soil water use and soil NO_3^--N. The reason for the lack of yield response by fall sweep plowing twice (tillage system 4) with increased soil NO_3^--N and soil water use is unknown. The harvest index was not affected by tillage system, but protein content of millet grain increased with higher soil NO_3^--N levels.

Cropping Sequence Comparisons: 1972–1977.

Table 6 summarizes the effect of tillage systems 1, 4, and 6 that were used in each of the five cropping sequences. Sweep plowing twice in the fall (system 4), and sweep plowing once plus atrazine at 1.12 kg/ha (system 6) increased soil NO_3^--N accumulation, soil water use, and millet grain yields compared to spring disking twice (system 1). The harvest index was not affected by tillage system. The tillage system resulting in the highest water use efficiency was fall sweep plowing + atrazine (system 6). This data demonstrates the value of initiating fall weed control by tillage or tillage and atrazine, which will increase stored soil water, and soil NO_3^--N accumulation. These factors, in turn, translate into increased proso millet grain production. Atrazine also may increase millet grain yields and water use efficiency by reducing weed infestations within the millet crop during the growing season.

Table 4. Effect of five tillage systems on millet, yield, harvest index, grain protein, and soil water use in the 1972-1973 and 1973-1974 cropping sequences.

Tillage system	Soil water use	Grain yield	Harvest index†	Protein content of grain
	mm	kg/ha		g/kg
1. Spring disk twice	140	1970	0.46	99
2. Spring sweep plow twice	132	1830	0.46	102
4. Fall sweep plow twice	168	2410	0.46	112
6. Fall sweep plow once, + atrazine at 1.12 kg/ha	155	2390	0.45	113
7. Fall sweep plow once, + 2,4-D ester at 2.24 kg/ha	152	2180	0.45	110
CV (%)	8.5	8.4	4.3	7.5
Single degree of freedom contrasts (*F* values)				
1 + 2 vs. 4 + 6 + 7	13.14**	26.30**	0.01	9.06*
4 vs. 6 + 7	1.56	1.15	0.01	0.01
6 vs. 7	0.06	2.77	0.01	0.70
1 vs. 2	0.99	1.23	0.01	0.23

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Harvest index = grain yield divided by biomass above ground.

Table 5. Effect of five tillage systems on proso millet yield, harvest index, protein content, soil NO_3^--N, and soil water use in the 1975-1976 and 1976-1977 cropping sequences.

Tillage system	Soil nitrate level at planting	Soil water use	Grain yield	Harvest index†	Protein content of grain
	kg/ha	mm	kg/ha		g/kg
1. Spring disk twice	67	104	1510	0.38	108
3. Fall and spring sweep plow	75	112	1680	0.39	115
4. Fall sweep plow twice	90	117	1520	0.38	123
5. Fall sweep plow once, + atrazine at 0.56 kg/ha	85	117	1700	0.38	113
6. Fall sweep plow once, + atrazine at 1.12 kg/ha	86	122	1830	0.39	120
CV (%)	6.1	11.9	6.5	4.8	2.1
Single degree of freedom contrasts (*F* values)					
1+3+4 vs. 5+6	9.08*	3.01	15.46**	0.01	1.21
1 vs. 3+6	26.65**	1.14	1.89	0.01	55.92**
5 vs. 6	0.16	0.01	2.91	0.01	0.54
3 vs. 4	21.04**	0.13	3.50	0.01	22.18**

*,** Significant at the 0.05 and 0.01 probability levels, respecctively.
† Harvest index = grain yield divided by total biomass above ground.

Table 6. Effect of three tillage systems on proso millet yield, harvest index, soil NO_3^--N, soil water use, and water use efficiency over five cropping sequences, 1972-1977.

Tillage system	Soil nitrate level at planting	Soil water use	Grain yield	Harvest index†	Water use efficiency
	kg/ha	mm	kg/ha		kg/ha per mm
1. Spring disk twice	61	110	1870	0.43	16.4
4. Fall sweep plow twice	87	129	2140	0.43	17.0
6. Fall sweep plow once + atrazine at 1.12 kg/ha	78	123	2300	0.43	18.4
CV (%)	5.8	9.8	7.5	3.8	8.6
Single degree of freedom contrasts (*F* values)					
1 vs. 4 + 6	82.30**	6.71*	17.77**	0.01	2.63
4 vs. 6	12.71**	0.12	2.32	0.01	2.52

*,** Significant at the 0.05 and 0.01 level, respectively.
† Harvest index = grain yield divided by total biomass above ground.

Table 7. Effect of N fertilizer and tillage system on proso millet production, averaged over two cropping seasons, 1974 and 1975.

Tillage system	Grain yields 0	Grain yields 42	Mean	Water use efficiency 0	Water use efficiency 42	Mean
	kg/ha			kg/ha per mm		
1. Spring disk twice	2270	2110	2190	18.3	18.1	18.2
4. Fall sweep plow twice	2620	2410	2515	18.4	18.0	18.2
6. Fall sweep plow once + atrazine at 1.12 kg/ha	2640	2720	2680	18.8	19.4	19.1
Mean	2510	2410		18.5	18.5	
CV (%)	8.9			9.6		
LSD 0.05 for tillage by fertilizer interaction: 420				No tillage × fertilizer interaction		
LSD 0.05 for fertilizer main effect: 24				No fertilizer effect		
Single degree of freedom contrasts (*F* values) for tillage systems				Single degree of freedom contrasts (*F* values) for tillage systems		
1 vs. 4 + 6	8.20**	13.10**		0.01	0.01	
4 vs. 6	0.02	4.56*		0.01	0.01	

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

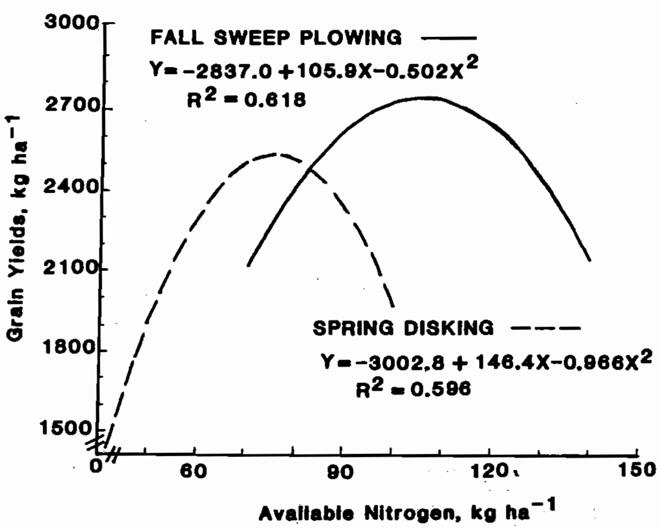

Fig. 1. Grain yield response of millet to available N (soil NO_3^- to a depth of 0.9 m plus fertilizer N, if applied) as influenced by tillage system.

Nitrogen Fertilizer Effect on Proso Millet Production.

In the 1974 and 1975 cropping seasons, N was applied to selected treatments to determine its effect on millet production in three different tillage systems. No significant N × year interactions occurred, so the data was averaged over the 2 yr. Adding N reduced grain yield (Table 7). This effect may have been caused by the high soil NO_3^--N levels at millet planting, which would have supplied the necessary N needed for optimal millet production within the available water regime present during this study. The N fertilizer may have stimulated excessive early vegetative growth resulting in inefficient use of available water. These results agree with those of Hinze (1977), who reported that millet probably would not respond to N fertilizer if grown in medium to heavy texture soils high in soil NO_3^--N. The addition of N may have also stimulated in-crop weed competition. Atrazine at 1.1 kg/ha would have eliminated these weeds, thus explaining the slight yield response to N fertilizer in tillage system 6 compared with tillage system 4. Water use efficiency was not affected by N fertilizer (Table 7). The tillage system effect on grain yield shown in Tables 4, 5, and 6 was also observed in this study. Millet grown after fall tillage (systems 4 and 6) yielded 14 to 29% more grain than millet grown after spring disk tillage (system 1).

Figure 1 shows the relationship between grain yield and available N (soil NO_3^- to a depth of 0.9; m plus fertilizer N if applied) as affected by tillage system. Two tillage systems were compared, fall sweep plowing twice (system 4) and spring disking (system 1). The data represents the five cropping sequences, plus the fertilizer treatments in cropping sequence 2 and 3, for both tillage systems. The second degree ploynominal curves indicate that more available N is needed to maximize millet grain yields when tillage is initiated in the fall. This increased N need for maximum grain yields for this tillage system is related to the increased soil water use, as over five cropping sequences, the soil water use by millet grown in the fall sweep plowing treatment was 19 mm greater than by millet grown in the spring disking treatment, an increase of 17% (Table 6).

CONCLUSIONS

Initiating weed control operations in the fall significantly increased proso millet production when compared with spring disking. The fall operations suppressed weed growth while increasing fall soil water storage and soil NO_3^--N levels. The interaction of these factors resulted in increased grain yields and protein content of grain. The water use efficiency by millet was also increased by fall operations. The addition of N fertilizer decreased proso millet grain production. This negative response to N fertilizer may have resulted from high soil NO_3^--N levels at planting time; thus, sufficient N was available without adding N fertilizer.

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