Reprinted from the *Journal of Production Agriculture*
Volume 12, no. 2, Apr.–June 1999
677 South Segoe Rd., Madison, WI 53711 USA

Winter Wheat and Proso Millet Yield Reduction Due to Sunflower in Rotation

D. C. Nielsen, R. L. Anderson, R. A. Bowman, R. M. Aiken, M. F. Vigil, and J. G. Benjamin

Research Question

Sunflower production offers central Great Plains producers an opportunity to diversify from the traditional winter wheat-fallow production system. But sunflower can leave the soil water profile in the top 72 in. very dry. The objective of this study was to determine the impact of sunflower on subsequent winter wheat or proso millet yields.

Literature Summary

Sunflower is adapted to the growing conditions of the central Great Plains and has an established market. But sunflower is a deep-rooted species capable of extracting large amounts of available water from deep in the soil profile. Yield of winter wheat and proso millet are linearly related to crop water use. Consequently, the low available soil water following sunflower production may reduce yield of subsequent wheat and millet crops.

Study Description

A crop rotation experiment was established near Akron, CO, in 1990. The following rotations were measured in 1995, 1996, and 1997 to quantify the effect of sunflower on subsequent winter wheat and proso millet yield: wheat-fallow (W-F), wheat-corn-fallow (W-C-F), wheat-sunflower-fallow (W-Sun-F), wheat-corn-sunflower-fallow (W-C-Sun-F), wheat-millet-sunflower-fallow (W-M-Sun-F), millet-corn (M-C), millet-sunflower (M-Sun), millet-wheat-corn (M-W-C). Soil water was measured at wheat and millet planting and harvest, and crop water use calculated by the water balance method. Wheat, millet, corn, and sunflower yields were taken at physiological maturity

Applied Questions

Does sunflower in rotation affect the amount of available soil water at wheat and millet planting?

Available soil water at wheat planting averaged about 2.3 in. lower in the W-C-Sun-F and W-M-Sun-F rotations compared with the W-F and W-C-F rotations, and about 4.3 in. lower in the W-Sun-F rotation compared with the W-F and W-C-F rotations. Available soil water at millet planting averaged about 1.4 in. lower in the M-Sun rotation compared with the M-C and M-W-C rotations.

Does the lower soil water at wheat and millet planting due to sunflower in rotation influence subsequent wheat and millet yields?

Wheat yield was reduced by about 179 lb/acre (3 bu/acre) for every in. less of available soil water at wheat planting (Fig. 1). Millet yield was reduced by about 296 lb/acre for every inch less of available soil water at millet planting. Average wheat yield in a W-Sun-F rotation was about 30% lower than wheat yield from W-C-Sun-F, W-M-Sun-F, W-C-F, and W-F (Fig. 2). Average millet yield in a M-Sun rotation was 43% lower than millet yield from M-W-C.

Recommendations

Producers should be aware that wheat yields in W-Sun-F rotations will almost always be lower than wheat yields in W-F production systems. On the other hand, when sunflower is only grown once every 4 yr (W-C-Sun-F, W-M-Sun-

Full scientific article from which this summary was written begins on page 193 of this issue.

F), wheat yields will probably only be reduced from the W-F yields when growing season precipitation is below normal. Additionally, including sunflower only once every 4 yr reduces pathogen and insect stresses on sunflower. Data from this study indicate that, on average, millet yields in a M-Sun rotation will be reduced about 43% from millet yields in a M-W-C rotation, but not greatly different from yields in a M-C rotation. In making decisions to include sunflower in crop rotations, producers should consider impact on subsequent crop yields, as well as costs of production, market value of crops, impact on pest problems, and total productivity of all of the crops in the rotation.

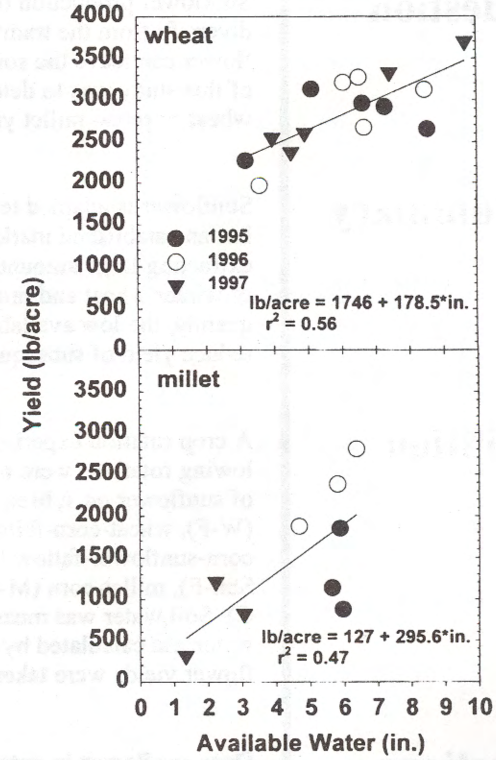

Fig. 1. Relationship between available soil water and grain yield. Top: winter wheat yield and available water at wheat planting in 0 to 71 in. depth; bottom: proso millet yield and available water at millet planting in 0 to 35 in. depth.

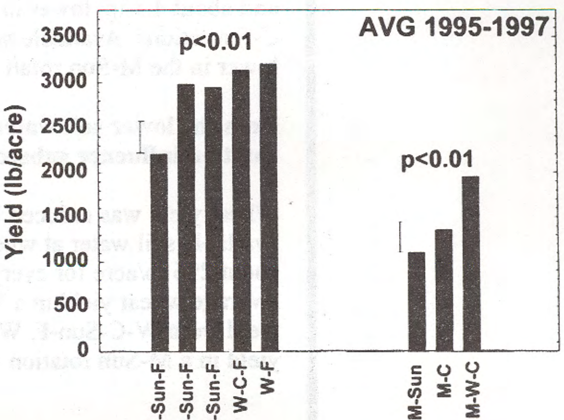

Fig. 2. Winter wheat and proso millet grain yield as affected by crop rotation at Akron, CO, averaged over 1995–1997 (*P* = probability of nonsignificant treatment differences, bars are LSD 0.10).

Winter Wheat and Proso Millet Yield Reduction Due to Sunflower in Rotation

D. C. Nielsen,* R. L. Anderson, R. A. Bowman, R. M. Aiken, M. F. Vigil, and J. G. Benjamin

Producers wishing to diversify crop production systems from the traditional winter wheat (*Triticum aestivum* L.)-fallow system of the central Great Plains need information regarding the impact of sunflower (*Helianthus annuus* L.) on subsequent winter wheat and proso millet (*Panicum miliaceum* L.) yields. This study was conducted to quantify winter wheat and proso millet yield reductions due to the lower available soil water that exists when sunflower is the prior crop in rotation. Eight crop rotations—including combinations of winter wheat (W), proso millet (M), corn (*Zea mays* L.) (C), sunflower (Sun), and fallow (F)—were established in 1990 and evaluated for yield, available soil water at planting, and crop water use in 1995, 1996, and 1997. The experiment was conducted at Akron, CO, on a Weld silt loam (fine, smectitic, mesic Aridic Paleustoll). Available soil water at wheat and millet planting was lower where sunflower had been the previous crop than where sunflower was not the previous crop. In dry years, rotations with sunflower as the previous crop had lower wheat and millet water use than other rotations, but averaged over 3 yr, there was no effect of sunflower on wheat or millet water use. Average wheat yield in a W-Sun-F rotation was about 30% lower than wheat yield from W-C-Sun-F, W-M-Sun-F, W-C-F, and W-F. Average millet yield in a M-Sun rotation was 43% lower than millet yield from M-W-C. Wheat yield declined by 178.5 lb/acre (3 bu/acre) for each inch decline in available soil water at planting. Millet yield declined by 295.6 lb/acre for each inch decline in available soil water at planting. In making the decision to include sunflower in crop rotations, producers will have to consider impact on subsequent crop yields, as well as costs of production, market value of crop, impact on pest problems, and total productivity of all crops in the rotation.

PRODUCERS in the central Great Plains have traditionally used a winter wheat-fallow production system in which one crop is grown every 2 yr. Recent studies have shown that more intense cropping systems (two crops in 3 yr, three crops in 4 yr, annual cropping) are possible when reduced or no tillage systems are used (Halvorson and Reule, 1994; Peterson et al., 1993; Halvorson et al., 1994; Anderson et al., 1999).

Sunflower is a crop adapted to the growing conditions of the central Great Plains (Nielsen, 1998a) and with a ready market (Anderson et al., 1999). Although sunflower residues are fragile, they are effective in controlling wind erosion and trapping snow during the winter, if left standing after harvest (Nielsen and Aiken, 1998; Nielsen, 1998b). However, sunflower is a deep-rooted species capable of extracting large amounts of available water from deep in the soil profile (Jaafar et al., 1993; Hattendorf et al., 1988; Unger, 1990; Connor and Hall, 1997; Blamey et al., 1997; Nielsen, 1998a).

Previous research has shown that the amount of available soil water influences crop water use, and that the yield of winter wheat and proso millet are linearly related to crop water use (Lyon et al., 1995; Shanahan et al., 1988; Nielsen and Halvorson, 1991; Nielsen, 1995). Consequently, the resulting low available soil water following sunflower production may have detrimental effects on subsequent winter wheat and proso millet yields. As producers begin to diversify cropping systems from winter wheat-fallow, they will require information regarding the effects of previous crops on subsequent crops in order to better determine optimum rotation sequence. Therefore, the objective of this experiment was to quantify winter wheat and proso millet yield reductions due to the lower available soil water that exists when sunflower is the prior crop in rotation.

MATERIALS AND METHODS

This study was conducted at the USDA Central Great Plains Research Station, 4 mi east of Akron, CO (45°09′N, 103°09′W, 4540 ft). The soil type is a Weld silt loam (fine, smectitic, mesic Aridic Paleustoll). In 1990, several rotations were established to investigate the possibility of cropping more frequently than every other year, as done with the traditional winter wheat-fallow system. A description of the plot area, tillage systems, and experimental design are given in Bowman and Halvorson (1997) and Anderson et al. (1999). Briefly, rotation treatments were established in a randomized complete block design with three replications. All phases of each rotation were present every year. Individual plot size was 30 ft by 100 ft, with east-west row direction. In the current analysis we used data from only 1995 to 1997, with the years of 1990 to 1994 used to establish rotation effects (Cady, 1991). Only the following rotations were used in this analysis to determine the influence of sunflower on subsequent winter wheat and proso millet water use and yield:

W-F, reduced till (2-yr)
W-C-F, reduced till (3-yr)
W-Sun-F, reduced till (3-yr)
W-C-Sun-F, reduced till (4-yr)
W-M-Sun-F, reduced till (4-yr)
M-C, no till (2-yr)
M-Sun, reduced till (2-yr)
M-W-C, no till (3-yr)

Details of the weed control practices comprising the reduced-till and no-till systems are given in Anderson et al. (1999). Briefly, the no-till system relied on contact and

USDA-ARS Central Great Plains Res. Stn., 40335 County Rd GG, Akron, CO 80720. Received 27 July 1998. *Corresponding author (dnielsen@lamar.colostate.edu).

Published in J. Prod. Agric. 12:193–197 (1999).

Abbreviations:; C, corn; F, fallow; LSD, least significant difference; M, proso millet; Sun, sunflower; W, winter wheat.

Table 1. Planting and harvest details, 1993–1997, Akron, CO.

Crop	Variety	Planting date	Seeding rate	Harvest date
			seeds/acre	
Wheat	TAM 107	20 Sep 1994	860 000	27 Jul 1995
	TAM 107	18 Sep 1995	870 000	12 Jul 1996
	Akron	28 Sep 1996	820 000	10 Jul 1997
Millet	Sunup	15 Jun 1995	740 000	14 Sep 1995
	Sunup	04 Jun 1996	740 000	03 Sep 1996
	Sunup	19 Jun 1997	880 000	04 Sep 1997
Corn	Pioneer 3732	29 Apr 1993	14 900	27 Oct 1993
	Pioneer 3732	06 May 1994	16 100	14 Oct 1994
	Pioneer 3732	18 May 1995	14 900	21 Oct 1995
	Pioneer 3732	01 May 1996	14 900	07 Oct 1996
	Pioneer 3732	01 May 1997	14 900	07 Oct 1997
Sunflower	Triumph 546	26 May 1993	16 600	14 Oct 1993
	Triumph 546	27 May 1994	16 600	27 Oct 1994
	Triumph 546	16 Jun 1995	14 900	18 Oct 1995
	Triumph 546	05 Jun 1996	20 300	23 Sep 1996
	Triumph 546	06 Jun 1997	20 300	28 Sep 1997

Table 2. Volumetric lower limits of soil water availability observed in plots (averaged over 1992–1996) and used to calculate available soil water.

Soil layer	Lower Limit	
	Wheat	Millet
in.	cu in/cu in	
0–12	0.170	0.170
12–24	0.120	0.129
24–36	0.072	0.087
36–48	0.061	0.067
48–60	0.082	0.086
60–72	0.111	0.119

residual herbicides for all weed control; reduced-till relied on combinations of residual and contact herbicides and sweep plow operations.

Fertilizer N was broadcast as ammonium nitrate to each plot before planting. Application rates were determined according to soil tests obtained each year and projected crop yield. Soil profiles were sampled in 12-in. increments to a depth of 6 ft. For wheat only, 15 lb P/acre (11-52-0) was banded with the seed at planting.

Table 1 gives the crop varieties, planting dates, seeding rates, and harvest dates for the wheat and millet analyzed in this study, plus the same information for the corn and sunflower crops grown prior to the wheat and millet.

Crop water use was calculated by the water balance method using soil water measurements and assuming runoff and deep percolation were negligible. The soil water measurements in the 0 to 12 in. layer were made by time-domain reflectometry. Soil water measurements at 18, 30, 42, 54, and 66 in. were made with a neutron probe. The neutron probe was calibrated against gravimetric soil water samples taken in the plot area. Gravimetric soil water was converted to volumetric water by multiplying by the soil bulk density for each depth. Two measurement sites were located near the center of each plot and data from the two sites were averaged to give one reading of soil water content at each sampling depth per plot.

Table 4. Monthly precipitation at Central Great Plains Research Station, Akron, CO, 1995–1997.

Month	1995	1996	1997	Average 1995–1997	Average 1908–1997
			in.		
January	0.86	0.30	0.52	0.56	0.34
February	0.34	0.02	0.53	0.29	0.34
March	0.87	1.13	0.07	0.69	0.83
April	2.46	0.48	0.85	1.26	1.66
May	5.72	4.57	2.19	4.16	3.03
June	4.76	2.55	3.15	3.48	2.51
July	1.52	3.24	1.21	1.99	2.69
August	0.78	2.67	3.36	2.27	2.05
September	2.26	3.39	0.98	2.21	1.24
October	0.41	0.48	2.31	1.07	0.91
November	0.58	0.02	0.26	0.29	0.55
December	0.09	0.03	0.44	0.19	0.41
Total	20.65	18.88	15.87	18.47	16.56
March–June	13.81	8.73	6.26	9.60	8.03
June–August	7.06	8.46	7.72	7.75	7.25

Available water per sampling depth was calculated as:

(Volumetric water – lower limit) × (layer thickness)

where

volumetric water = cu in. water/cu in. soil from neutron probe or time-domain reflectometry

Lower limit = lowest volumetric water observed in plots for an individual crop (Ritchie, 1981; Ratliff et al., 1983)

Layer thickness = 12 in.

The specific values of lower limit used for wheat and millet were determined from observations on plots in the experimental area from 1992 through 1996 (Table 2).

Data were analyzed for treatment (rotation) differences by analysis of variance, with years considered as a fixed variable (Gomez and Gomez, 1984). When treatment differences were significant ($P < 0.10$ from analysis of variance), $LSD_{0.10}$ was computed to perform mean separations. The effect of differences in available water content at planting on wheat and millet yield was analyzed by linear regression.

RESULTS AND DISCUSSION

Wheat water use was significantly different between years ans between rotations, with a significant year × rotation interaction (Table 3). Millet water use was significantly different between years, but not significantly affected by rotation. There was a significant year × rotation interaction.

The 3 yr of the study were somewhat different in timing and amount of precipitation (Table 4). Precipitation during the wheat growing season (March–June) was 172% of normal in 1995, 109% of normal in 1996, and 78% of normal in 1997. Precipitation during the millet growing season

Table 3. Values of *P* from Analysis of Variance tables for winter wheat and proso millet water use, available water at planting, and yield following sunflower, 1995–1997, Akron, CO.

Source of variation	Wheat water use	Millet water use	Wheat available water	Millet available water	Wheat yield	Millet yield
			P			
Year	<0.01	<0.01	0.96	<0.01	0.04	<0.01
Rotation	<0.01	0.19	<0.01	0.04	<0.01	<0.01
Year × rotation	0.03	0.06	<0.01	0.78	0.06	0.45

(June–August) was 97% of normal in 1995, 117% of normal in 1996, and 107% of normal in 1997.

Because of the above normal rainfall during the 1995 wheat growing season, wheat water use was not affected by crop rotation (Fig. 1). There was also no statistically significant difference in wheat water use in 1996 due to crop rotation. However, the mean values of water use were lowest in W-Sun-F and highest in W-F. In 1997, the driest of the 3 yr, there was a significant rotation effect on wheat water use, with all rotations that included sunflower using less water than the rotations without sunflower. Average wheat water use over the 3 yr of the study was significantly different due to crop rotation. The range of mean values was 16.3 in. (W-Sun-F) to 19.4 in. (W-F). The W-C-Sun-F, W-M-Sun-F, and W-C-F rotations all showed a mean wheat water use of about 17.5 in.

Millet water use in 1995 was highest in the M-W-C rotation, with no difference between M-Sun and M-C (Fig. 1). In 1996, the highest water use occurred in M-C, with no difference in water use between M-Sun and M-W-C. There were no rotation differences in water use during 1997. Average millet water use over the 3 yr of the study was not significantly different due to crop rotation, but the range of mean values was 10.7 in. for M-Sun to 12.7 in. for M-W-C.

Available soil water at wheat planting was not different between years, but was significantly different by rotation; there was a significant year × rotation interaction for available water at wheat planting (Table 3). Available soil water at millet planting was significantly different between years and rotations, but the year × rotation interaction was not significant.

Sunflower ahead of wheat and millet resulted in significantly lower available water (averaged over 3 yr) at wheat and millet planting (Fig. 2). The average available soil water at wheat planting for the W-Sun-F rotation was 4.6 in. less than for the W-F rotation, and 3.9 in. less than for the W-C-F rotation. Available water at planting for W-C-Sun-F and W-M-Sun-F was significantly greater than W-Sun-F and significantly lower than W-C-F. We speculate that the greater available water at wheat planting following sunflower in a 4-yr rotation vs. following sunflower in a 3-yr rotation may be due to the better standability of sunflower stalks over winter (and greater snow catch) where diseases and pest problems were lower due to the less frequent appearance of sunflower in the 4-yr rotations (Anderson et al., 1999; Nielsen, 1998b). Available water at millet planting was lowest for the M-Sun rotation, about 1.4 in. lower than M-C and M-W-C.

The significant reductions in available soil water at wheat and millet planting following sunflower are primarily a result of the lower amounts of available water below the 35 in. soil depth. Sunflower's ability to extract water from deeper in the soil profile than other crops is evident in these data (Jaafar et al., 1993; Unger, 1990).

Wheat yields were significantly different between years and between rotations, with a significant year × rotation interaction (Table 3). Wheat yields (Fig. 3) showed a statistically significant rotation effect in 1996 and 1997. In 1997,

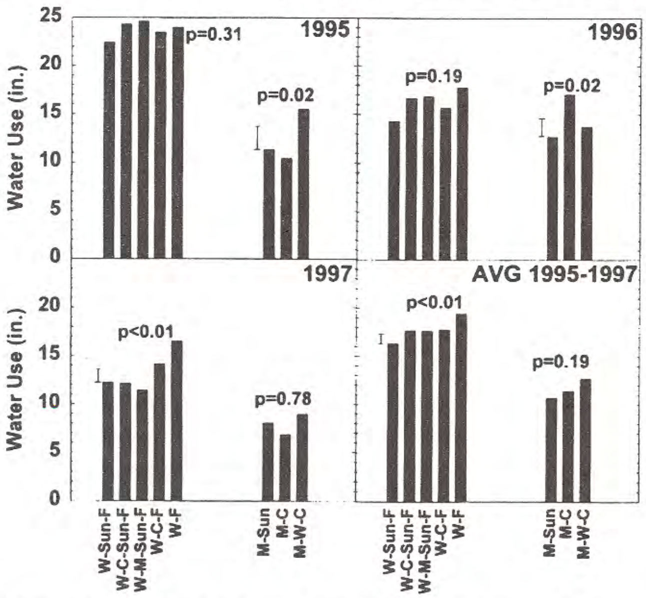

Fig. 1. Winter wheat and proso millet water use as affected by crop rotation in 1995, 1996, 1997, and 3-yr average at Akron, CO (P = probability of nonsignificant treatment differences, bars are $LSD_{0.10}$).

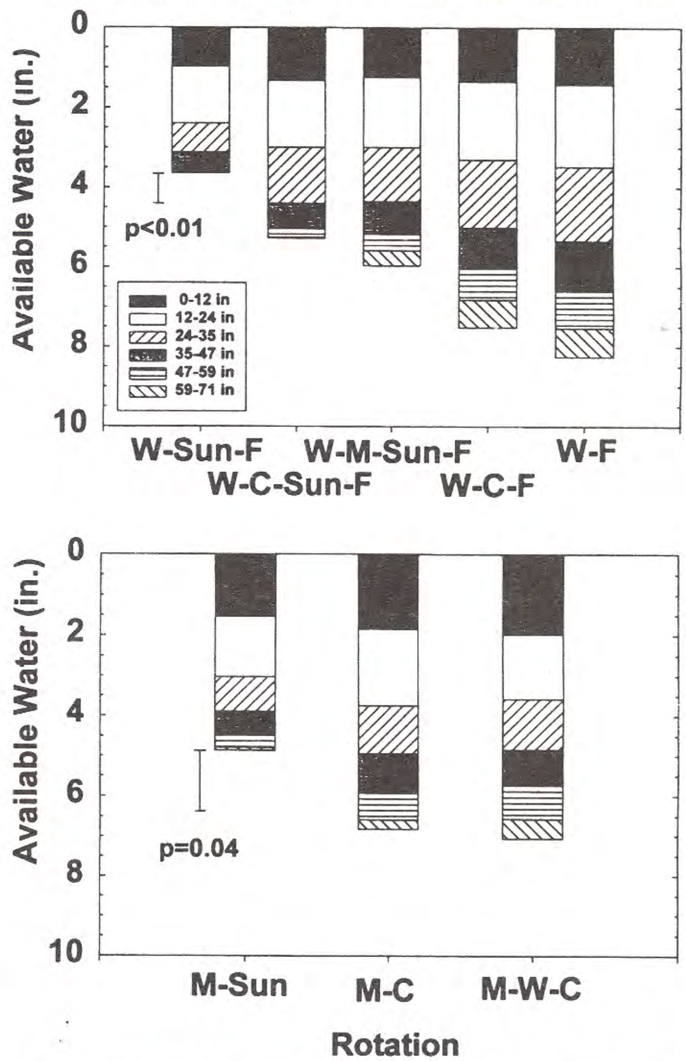

Fig. 2. Available soil water by depth in soil (averaged over 1995–1997) at winter wheat planting (top) and proso millet planting (bottom) (P = probability of nonsignificant treatment differences, bars are $LSD_{0.10}$).

the driest of the 3 yr, all three rotations that included sunflower had yields that were significantly lower (approximately 30%) than the yields from W-F and W-C-F. In 1995 (above normal wheat growing season rainfall), there were no statistically significant yield reductions due to crop rotation. However, in all 3 yr, the lowest wheat yields were observed in the W-Sun-F rotation. The average wheat yield

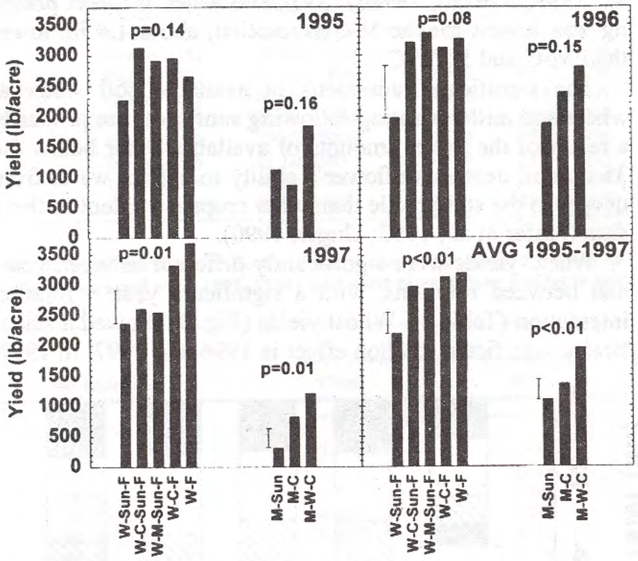

Fig. 3. Winter wheat and proso millet grain yield as affected by crop rotation in 1995, 1996, 1997, and 3-yr average at Akron, CO (P = probability of nonsignificant treatment differences, bars are $LSD_{0.10}$).

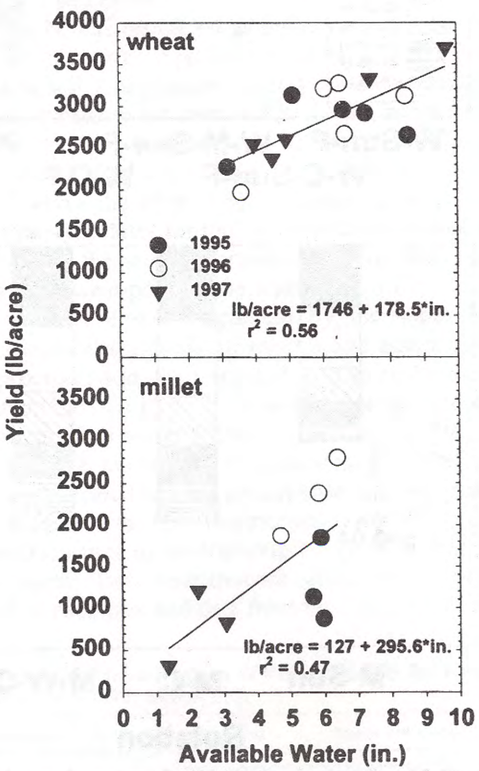

Fig. 4. Relationship between available soil water and grain yield. Top: winter wheat yield and available water at wheat planting in 0 to 71 in. depth; bottom: proso millet yield and available water at millet planting in 0 to 35 in. depth.

for the 3 yr of the study was similar for all rotations, except for W-Sun-F, which was approximately 30% lower than W-F and W-C-F.

Millet yields were significantly different between years and between rotations, but the year × rotation interaction was not significant (Table 3). Millet yields showed a statistically significant difference due to rotation only in 1997. In that year, yield from M-Sun was 74% lower than yield from M-W-C. In all 3 yr, the highest yield came from the M-W-C rotation. The average millet yields for the 3 yr of the study were lowest for M-Sun and highest for M-W-C.

Yields of both winter wheat and proso millet were significantly correlated (P = 0.001, wheat; P = 0.040, millet) with available soil water at planting (Fig. 4). Figure 4 uses an available water total measured in the 0 to 71 in. profile for wheat and in the 0 to 35 in. profile for millet because those are the typical water extraction depths observed for those crops on this soil at this location. Wheat yield declined by 178.5 lb/acre (3 bu/acre) for each inch decline in available soil water at planting. Millet yield declined by 295.6 lb/acre for each inch decline in available soil water at planting. Lyon et al. (1995) reported a lower response of millet yield to available soil water at planting (190.0 lb/acre per in.) over a range of 5.9 to 11.4 in. of available water in the

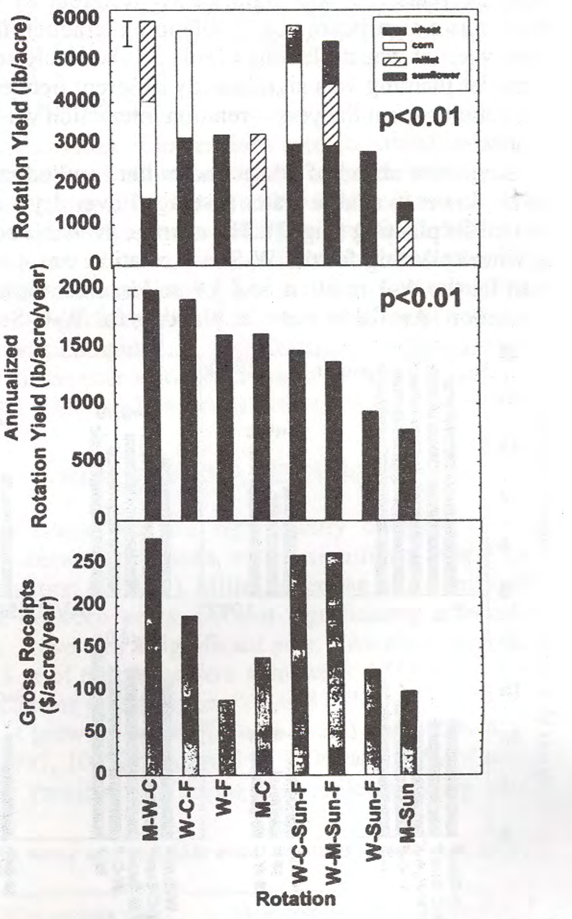

Fig. 5. Rotation grain yields and gross receipts averaged over 1995 to 1997, Akron, CO. Top: winter wheat, corn, proso millet, and sunflower yields; middle: annualized rotation yield (total pounds of production averaged over number of years of rotation); bottom: gross receipts of crops in rotation assuming wheat at $3.35/bu, corn at $2.25/bu, sunflower at $11.00/cwt, and millet at $4.70/cwt.

top 48 in. of the soil profile. Their data showed available soil water at planting explained 79% of the millet yield variability. The large difference in millet yields between 1995 and 1996 in the current study is partially attributable to the 20% higher growing season precipitation and 300% higher precipitation during heading, flowering, and grain-filling in 1996 compared with 1995.

While it is clear that average yields of both wheat and millet are lowered by the presence of sunflower in rotation, the yield of the total rotation must be considered when making decisions about diversifying and intensifying cropping systems. The rotation yield averaged over 1995 through 1997 (Fig. 5, top) shows M-W-C, W-C-F, W-C-Sun-F, and W-M-Sun-F to be the top producing rotations based upon total pounds of grain produced and M-Sun to be the lowest producing rotation. When these yields are expressed on an annualized basis (Fig. 5, middle) (which accounts for the average yield across all crops in the rotation and the fallow year when it occurs), M-W-C and W-C-F are the top yielding rotations (1992 to 1913 lb/acre per year), followed by W-F, M-C, W-C-Sun-F, and W-M-Sun-F (1612 to 1371 lb/acre per year). The lowest yielding rotations were W-Sun-F and M-Sun (930 to 771 lb/acre per year). These two rotations may be too demanding of water to be successfully used in the central Great Plains. However, it has been our observation that in larger sunflower production fields with good standing residue following harvest, and with normal to above normal snowfall, soil water recharge of 4 to 6 in. can occur (Nielsen, 1998b). This soil water recharge by snow deposition can reduce the impact of sunflower on subsequent wheat and millet yields from what we have observed in this small plot experiment.

We compared the gross value of the crops produced in the eight rotations using the following 15-yr average (1983–1997) prices paid to farmers at harvest (USDA-Agricultural Marketing Service, Greeley, CO, 1998, personal communication): wheat, \$3.35/bu; corn, \$2.25/bu; sunflower, \$11.00/cwt; millet, \$4.70/cwt. Gross value of the crops produced in the M-W-C, W-C-Sun-F, and W-M-Sun-F rotations were similar (\$260 to \$280/acre per year) (Fig. 5, bottom). The lowest value cropping systems were W-F (\$90/acre per year) and M-Sun (\$100/acre per year).

CONCLUSIONS

Sunflower extracts large amounts of water from deep in the soil profile, thereby lowering the amount of stored soil water available at wheat and millet planting time. This lower amount of stored soil water can lead to reduced wheat and millet yields in years where growing season rainfall is low, compared with rotations without sunflower. Lowest wheat yields always occurred in the W-Sun-F rotation. Four-year rotations that include sunflower (W-C-Sun-F, W-M-Sun-F) show less sunflower impact on wheat yields than a 3-yr rotation (W-Sun-F). On average, millet yield in a M-Sun rotation was only 56% of millet yield in a M-W-C rotation. In making the decision to include sunflower in crop rotations, producers will have to consider impact on subsequent crop yields, as well as costs of production, market value of crop, impact on pest problems, and total productivity of all of the crops in the rotation.

ACKNOWLEDGMENTS

We express our appreciation to G. Lindstrom, T.J. Army, A.D. Halvorson, S.E. Hinkle, G.A. Peterson, and D.G. Westfall for their contributions to the design of this study. We also thank Gene Uhler, Albert Figueroa, Karen Couch, Hubert Lagae, Curt Reule, Delbert Koch, Bob Florian, Cindy Johnson, Linda Hardesty, Donna Fritzler, Michele Harms, Stephanie Hill, Donna Diamond, Kate Drullinger, and Marrietta Koch for technical support.

REFERENCES

Anderson, R.L., R.A. Bowman, D.C. Nielsen, M.F. Vigil, R.M. Aiken, and J.G. Benjamin. 1999. Alternative crop rotations for the central Great Plains. J. Prod. Agric. 12:95–99.

Blamey, F.P.C., R.K. Zollinger, and A.A. Schneiter. 1997. Sunflower production and culture. p. 595–670. *In* A.A. Schneiter (ed.) Sunflower technology and production. Agron. Monogr. 35. ASA, CSSA, and SSSA, Madison, WI.

Bowman, R.A., and A.D. Halvorson. 1997. Crop rotation and tillage effects on phosphorus distribution in the central Great Plains. Soil Sci. Soc. Am. J. 61:1418–1422.

Cady, F.B. 1991. Experimental design and data management of rotation experiments. Agron. J. 83:50–56.

Connor, D.J., and A.J. Hall. 1997. Sunflower physiology. p. 113–182. *In* A.A. Schneiter (ed.) Sunflower technology and production. Agron. Monogr. 35. ASA, CSSA, and SSSA, Madison, WI.

Gomez, K.A., and A.A. Gomez. 1984. Statistical procedures for agricultural research. 2nd ed. John Wiley and Sons, New York.

Halvorson, A.D., R.L. Anderson. S.E. Hinkle, D.C. Nielsen, R.A. Bowman, and M.F. Vigil. 1994. Alternative crop rotations to winter wheat-fallow. p. 6–11. *In* J.L. Havlin (ed.) Proc. Great Plains Soil Fertility Conf., Vol. 5, Denver. 7–8 Mar. Kansas State Univ., Manhattan.

Halvorson, A.D., and C.A. Reule. 1994. Nitrogen fertilizer requirements in an annual dryland cropping system. Agron. J. 86:315–318.

Hattendorf, M.J., M.S. Redelfs, B. Amos, L.R. Stone, and R.E. Gwin, Jr. 1988. Comparative water use characteristics of six row crops. Agron. J. 80:80–85.

Jaafar, M.N., L.R. Stone, and D.E. Goodrum. 1993. Rooting depth and dry matter development of sunflower. Agron. J. 85:281–286.

Lyon, D.J., F. Boa, and T.J. Arkebauer. 1995. Water-yield relations of several spring-planted dryland crops following winter wheat. J. Prod. Agric. 8:281–286.

Nielsen, D.C. 1995. Water use/yield relationships for central Great Plains crops. Conserv. Tillage Fact Sheet no. 2-95. Cent. Great Plains Res. Stn., Akron, CO.

Nielsen, D.C. 1998a. Comparison of three oilseed crops for the central Great Plains. J. Prod. Agric. 11:336–341.

Nielsen, D.C. 1998b. Snow catch and soil water recharge in standing sunflower residue. J. Prod. Agric. 11:476–480.

Nielsen, D.C., and R.M. Aiken. 1998. Wind speed above and within sunflower stalks varying in height and population. J. Soil Water Conserv. 53:347–352.

Nielsen, D.C., and A.D. Halvorson. 1991. Nitrogen fertility influence on water stress and yield of winter wheat. Agron. J. 83:1065–1070.

Peterson, G.A., D.G. Westfall, and C.V. Cole. 1993. Agroecosystem approach to soil and crop management research. Soil Sci. Soc. Am. J. 57:1354–1360.

Ratliff, L.F., J.T. Ritchie, and D.K. Cassel. 1983. A survey of field-measured limits of soil water availability and related laboratory-measured properties. Soil Sci. Soc. Am. J. 47:770–775.

Ritchie, J.T. 1981. Soil water availability. Plant Soil 58:327–338.

Shanahan, J.F., R.L. Anderson, and B.W. Greb. 1988. Productivity and water use of proso millet grown under three cropping rotations in the central Great Plains. Agron. J. 80:487–492.

Unger, P.W. 1990. Sunflower. p. 775–794. *In* B.A. Stewart and D.R. Nielsen (ed.) Irrigation of agricultural crops. Agron. Monogr. 30. ASA, CSSA, and SSSA, Madison, WI.