IMPACT OF DIVERSIFIED ROTATION ON CORN N UPTAKE, YIELD, AND SOIL QUALITY

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ABSTRACT

Increased length of rotation and increased crop diversity may improve efficiency of water and nitrogen (N) use by corn (*Zea mays* L.) and soil quality. Objectives were to determine the effect of diversified crop rotation on: 1) N-fertilizer use efficiency (NUE) of corn, 2) water use efficiency (WUE) of corn, and 3) temporal change in soil quality attributes. An experiment was started in 1997 on a Barnes clay loam (fine-loamy, mixed, superactive, frigid Calcic Hapludoll) near Brookings, South Dakota. All rotations are under no tillage. Rotations were continuous corn (CC), corn-soybean [*Glycine max* (L.) Merr.] (CS), a 3-year rotation of corn-soybean-oat/pea (*Avena sativa* L. and *Pisum sativum* L. mix) hay (CSH), a 3-year rotation of corn-soybean-spring wheat (*Triticum aestivum* L.) (CSW), and a 5-year rotation of corn-soybean-oat/pea hay companion seeded with alfalfa (*Medicago sativa* L.)-alfalfa-alfalfa (CSHAA). Fertilizer N has been applied at the same rate to all rotations. Average (years) starter N was 16 kg N ha^{-1}, with an additional 62 kg N ha^{-1} side dressed as ammonia nitrate. Average corn grain yield (1998-2003) was significantly (p=0.001) greater under CSW (6790 kg ha^{-1}) compared with CC (4000 kg ha^{-1}). Yield was not different among CSH, CSW, and CSHAA rotations. Water use efficiency was significantly (p=0.001) greater under CSH and CSW and ordered as CSW>CSH>CS=CSHAA>CC. Nitrogen use efficiency was significantly (p=0.002) less under CC compared with other rotations. There were no differences among rotations in total soil C and N in the top 15 cm. Average (rotations) C:N ratio significantly narrowed across years. There were no differences (in 2003) among rotations in soil organic matter (loss on ignition), however particulate organic matter (POM) was significantly (p=0.002) greater under CSHAA compared with other rotations. Diversified rotations have potential to increase corn yield and efficiency of water and N use. Further, increased rotation diversity improved some soil attributes associated with soil quality.

INTRODUCTION

Profit margins for production of most crops are very narrow and producers seek sustainable cropping systems that provide consistent return on investment. Nitrogen has been considered as one of the best input investments that a farmer can make in terms of return on dollars spent. Bundy et al. (1999) estimated that in the 12 states of the North Central United States, at least 4 million tons of N fertilizer are applied annually to corn at a cost of about 800 million dollars. Thus, there is substantial justification to improve N management in the North Central Region of the USA Objectives were to determine effect of rotation on soil C sequestration, WUE, and NUE of corn in the northern Corn Belt.

MATERIAL AND METHODS

The study was located on the Eastern South Dakota Soil and Water Research Farm near Brookings, South Dakota on a Barnes clay loam with nearly level topography. Plots (rotations) were arranged as a randomized complete block with four replications. Plots were 12 m long x 12 m wide. All phases of each rotation were present every year. Tillage has not been used since 1997. Triple super phosphate (0-45-0) equivalent to 89 kg ha^{-1} of elemental P was broadcast on all plots in October 1997.

Crop rotations were: continuous corn, corn-soybean, a 3-year rotation of corn-soybean-oat/pea hay, a 3-year rotation of corn-soybean-spring wheat, and a 5-year rotation of corn-soybean-oat/pea hay companion seeded with alfalfa-alfalfa-alfalfa. In CSHAA rotation, oat/pea was used as annual hay and as a companion crop to establish alfalfa. A mix of oat and pea was seeded for oat-pea hay. We aimed for a ratio (viable seeds) of about 200 oat seeds to 100 pea seeds per m^2 following recommendations of Chapko et al. (1991). Actual seeding rate, on a mass basis, varied year to year depending upon seed weight of cereal and pea.

Average (1998-2003) application of fertilizer N was 16 kg ha^{-1} as starter (14-16-11) with the seed, and 60 kg ha^{-1} as side dress (ammonia nitrate, 34-0-0) to all rotations. A low rate of N fertilizer has been used so as not to mask effect of crop rotation on corn yield. Available N for the corn crop was defined as the sum of soil nitrate-N plus fertilizer N, and this sum does not include N (as N credit) from the previous crop (Gerwing and Gelderman, 1996). Soil nitrate-N was measured in the top 1.2 m. Nitrogen use efficiency was calculated as the ratio of corn grain yield to available N.

Soil samples for nitrate-N were collected in fall (late October to November) to a depth of 120 cm at increments of 0 to 15 cm, 15 to 30 cm, 30 to 60 cm, 60 to 90 cm, and 90 to 120 cm. Three samples were taken randomly from each depth on each plot. Nitrate-N was measured using 2 M KCl extraction and copperized Cd reduction column procedure (Zellweger Analytics, 1992).

Grain yields were measured with a Massey Ferguson MF 8-XP research plot combine (Kincaid Equipment Manufacturing[1], Haven, Kansas) equipped with an electronic weigh bucket. On each plot, 4 rows, 12 m long were harvested for grain yield. Corn grain yields were adjusted to 15.5% moisture. Grain moisture was measured using a Dickey-John (Dickey-John Corp., Auburn, IL) grain moisture meter. Grain oil and protein were measured using a near-infrared spectrometer (Foss Corp., Silver Spring, MD).

Soil water content in the top 1.8 m was measured using neutron attenuation equipment to determine water storage and use. Neutron equipment was calibrated in a manner described by Pikul and Aase (1998). Water use was defined as beginning soil water content minus ending soil water content plus precipitation during the growing season. Operationally, this period was defined as 1 June through 30 September. Water use efficiency was calculated as the ratio of corn grain yield to water use.

Soil C and N were measured on samples collected from the 0 to 7.5 cm and 7.5 to 15 cm depths in 1997, 1999, and 2001 using a LECO 2000 C-N analyzer (St Joseph, Michigan). Total C was considered to be total organic C because average soil pH of the top 15 cm was less than 7.

Soil particulate organic matter (POM) of six aggregate sizes were measured (Cambardella and Elliot, 1992) on samples from the top 5 cm of soil. About 10 kg of soil was

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[1] Mention of trade names is for the benefit of the reader and does not constitute endorsement by the U.S. Department of Agriculture over other products not mentioned.

collected in 2003 from each plot in the corn phase of rotation. A rotary sieve (Chepil, 1962) was used to separate soil into aggregate groups. Group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2.0 mm, group 4 was 2.0-6.0 mm, group 5 was 6.0-19.0 mm, and group 6 was >19.0 mm.

Data were analyzed using 2-way ANOVA (year and rotation) and means separated using least significant differences. A probability (p) level ≤ 0.10 was considered significant.

RESULTS AND DISCUSSION

There was a significant corn-yield response to rotation. Greatest corn yield (average of 6 years) was under CSW at 6790 kg ha^{-1} (Table 1) and this yield was significantly greater than under CC and CS. There were no differences between CSW, CSHAA (6060 kg ha^{-1}) and CSH (6470 kg ha^{-1}). Yearly corn yield (average of all rotations) has ranged from a low of 2860 kg ha^{-1} to a high of 7990 kg ha^{-1} . Precipitation and growing degree days are shown in Table 2.

Table 1. Soil water at the beginning of the corn growing season (aprox. 1 June), soil nitrate-N following the previous crop (aprox. 1 November), difference in soil nitrate-N from previous fall, corn yield, corn water use efficiency (WUE), corn nitrogen use efficiency (NUE), corn grain moisture at harvest, grain oil, and grain protein. Rotations (R) include continuous corn (CC), corn-soybean (CS), corn-soybean-hay (CSH), corn-soybean-hay-alfalfa-alfalfa (CSHAA), and corn-soybean-wheat (CSW).

	Soil water in 0-1.8 m	Soil nitrate-N in 0-1.2 m	Soil Nitrate-N difference	Yield at 15.5% moisture	WUE	NUE	Grain moisture	Grain oil	Grain protein
Rotation	mm	kg-N/ha	kg-N/ha	kg/ha	kg/ha/ mm	kg/kg-N	%	%	%
CC	521 b	47 a	-0.7 b	4000 a	12.5 a	32.2 a	18.8 c	4.13 c	9.09 a
CS	524 b	49 a	-1.7 b	6000 b	18.1 b	48.3 b	17.0 b	3.94 b	9.33 bc
CSH	492 ab	68 b	-20.6 a	6470 cb	19.9 cb	46.0 b	16.6 ab	3.95 cb	9.53 c
CSHAA	465 a	50 a	39.8 c	6060 cb	18.1 b	47.8 b	16.0 a	3.72 a	10.15 d
CSW	521 b	66 b	-13.8 a	6790 c	20.5 c	48.2 b	17.1 b	4.04 cb	9.25 ab
Year									
1998	533	54	-25.0	7990	26.0	64.4	18.0		
1999	550	51	-3.7	6700	18.4	50.4	16.2		
2000	503	36	44.7	6270	18.8	54.2	14.4		
2001	534	86	-30.6	5480	14.8	33.9	15.7	3.92	8.47
2002	524	45	17.6	2860	8.6	23.4	21.0	4.10	9.74
2003	384	63		5890	20.4	40.7	17.4	3.86	10.20
p-value									
Rotation	0.076	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
Year (Y)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
R X Y	ns	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Grain quality, evaluated by measuring moisture, oil, and protein, was different among rotations (Table 1). Moisture at harvest was significantly greater under CC compared with other rotations. Lowest grain moisture occurred under CSHAA, and grain from this rotation had significantly more grain protein compared with other rotations.

Table 2. Growing degree days and precipitation for May through September.

	1998	1999	2000	2001	2002	2003
Month	-------------- Growing degree days (base 50° F) ----------------					
May	414	333	325	295	237	249
June	413	490	446	492	575	450
July	617	680	622	699	736	626
Aug.	597	576	597	609	577	616
Sept.	468	350	374	397	417	319
Season total	2509	2429	2364	2492	2542	2260
	------------------------ Precipitation (mm) ------------------------					
May	39	87	171	49	78	70
June	52	66	76	93	62	84
July	40	69	45	66	71	70
Aug.	89	47	41	19	100	56
Sept.	19	72	23	57	35	88
Season total	240	341	357	283	347	368
Yearly total	475	526	568	575	591	471

Corn yield response to available N was not significantly different among CSW, CSHAA, CSH, and CS. Nitrogen use efficiencies for these rotations were ordered such that CS> CSW> CSHAA> CSH (Table 1). Continuous corn had the lowest NUE at 32.2 kg grain / kg N. The similarity of NUE values among rotations, except CC, suggests that there were no differences in the amount of nitrogen transformed (mineralized) from organic to inorganic forms during the growing season. A simplistic conclusion might be that this soil is in transition (unstable C:N ratio) and will require several more years before a rotation benefit is realized.

In the past 6 years, there were no differences in N fertilizer applied to rotations and there were only small, but significant, differences in soil nitrate-N in the fall following the crop before corn (Table 1). Three year rotations of CSH and CSW had the highest soil nitrate-N in fall before the corn year at 68 and 66 kg-N ha^{-1}, respectively. In autumn, following corn, all rotations except CSHAA showed a net extraction of nitrate-N from the soil profile (indicated with a negative sign in Table 1). In CSHAA, average (6 years) nitrate-N following corn was 40 kg-N ha^{-1}. The NUE values for corn under CSHAA does not show a rotation benefit for corn following two years of alfalfa (Table 1), and this result was not expected. Accumulation of soil nitrate-N under CSHAA (positive value shown in Table 1) suggests: 1) water supply limited plant uptake of fertilizer N, or 2) newly mineralized N is being quickly tied up (unavailable during the growing season).

Water and available N are the most important factors that govern yield and one or the other can limit growth. Seasonal evapotranspiration under alfalfa hay may be at least twice that of maize. Corn yield on the CSHAA has been less than CSH and CSW and this may be a consequence of less soil water at the start of the corn season under CSHAA (Table 1). Average (all years) soil water under CSHAA was 465 mm. In contrast, soil water under CSW, the highest yielding rotation, has been 521 mm. Corn grown under CSHAA has had the lowest soil moisture and highest grain protein at harvest (Table 1).

There was no significant rotation effect on soil C sequestration, nor was there a clear trend in soil C in the top 15 cm following four years of no tillage (comparison of samples collected in 1997, 1999, and 2001, data not shown). Among rotations, there were no differences in total soil N in the top 15 cm (data not shown). However, there was a significant year effect for total soil N in the 0 to 7.5 cm and 7.5 to 15 cm depths. Increase in soil N resulted in a narrowing of the C:N ratio. In the top 7.5 cm, C:N for 1997, 1999, and 2001 was 11.13, 10.90, and 10.41, respectively. For the 7.5 to 15 cm depth, C:N was 11.14, 10.86, and 10.56 for 1997, 1999, and 2001, respectively. These C:N ratios show that this soil is in transition following the change to no tillage. Further, these changing C:N ratios might explain the relatively poor showing of corn yields under CSHAA and CSH compared with corn under CSW.

Table 3. Fine particulate organic matter (POM) and total POM of soil aggregates collected from the top 5 cm. Rotations were continuous corn (CC), corn-soybean (CS), corn-soybean-hay (CSH), corn-soybean-hay-alfalfa-alfalfa (CSHAA), and corn-soybean-wheat (CSW).

	Aggregate size groups†					
	1	2	3	4	5	Average
	---Fine POM (0.053-0.5 mm) as percent of SOM---					
Rotation						
C	9.66 a	9.35 ab	7.58 a	8.62 a	8.55 a	8.65 a
CS	9.61 a	8.22 a	7.63 a	8.93 a	8.94 a	8.63 a
CSH	11.08 ab	9.24 ab	8.00 a	9.50 ab	8.43 a	9.13 ab
CSHAA	13.34 c	11.05 c	10.38 b	14.68 c	12.07 b	11.73 c
CSW	13.20 bc	10.10 bc	9.82 b	11.90 b	9.29 a	10.27 bc
p-value	0.020	0.075	0.005	0.001	0.010	0.002
	---Total POM as percent of SOM---					
C	9.80 a	13.58 b	14.50 abc	12.45 ab	10.28 a	11.72 ab
CS	9.73 a	11.14 a	12.33 ab	11.00 a	10.48 a	10.78 a
CSH	11.18 a	13.17 ab	12.12 a	11.68 a	9.59 a	11.22 ab
CSHAA	13.8 b	17.40 c	16.88 c	19.10 c	13.81 b	15.18 c
CSW	13.58 b	15.13 cb	16.13 bc	15.07 b	10.81 a	13.14 b
p-value	0.015	0.001	0.044	0.001	0.026	0.002

†Aggregates in group 1 were < 0.4 mm, group 2 were 0.4-0.8 mm, group 3 were 0.8-2 mm, group 4 were 2-6 mm, group 5 were 6-19 mm, and group 6 (not shown) were > 19 mm.

Soil improvement is a slow process and measurable changes in soil condition may take several years. Particulate organic matter (POM) is a component of the labile soil organic matter pool, and has been used as an indicator of soil quality. This measurement is valuable because it is a sensitive indicator of short-term (unlike total soil carbon) changes in soil condition. Further, increased levels of POM are associated with improved nutrient mineralization and aggregate stability (Liebig et al., 2002). Distributions of fine POM and total POM among soil aggregates and rotations are shown in Table 3. Among rotations, CSHAA and CSW have added significantly more, when compared with CC, CS, and CSH, fine and total POM to all aggregate classes in the top 5 cm of soil.

CONCLUSION

Diversified crop rotations have potential to increase NUE and reduce fertilizer N requirements for corn, but there is a poor understanding of associated effects on soil condition. Long-term field experiments provide benchmarks on crop response, soil quality, and the time frame associated with change. After four years of no tillage, there were no significant differences among crop rotations in soil C. However, soil productivity is related to quantity and quality of soil organic matter. The ratio of soil C:N has consistently narrowed on all rotations and this may be a consequence of no tillage. The similarity of NUE values among rotations, except CC, suggests that there were no differences in the amount of nitrogen transformed (mineralized) from organic to inorganic forms during the growing season, and this finding might reflect that the soil is in transition (unstable C:N ratio) and will require several more years before a rotation benefit is realized.

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