Crop Yield as Affected by Rotation and Nitrogen Rate. III. Corn

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ABSTRACT

Corn (*Zea mays* L.) is a widely grown crop in the USA that responds positively to crop rotation. This study compares yields of corn grown in continuous monoculture with that of a (i) 2-yr soybean [*Glycine max* (L.) Merr.]-corn rotation; (ii) a 4-yr soybean-grain sorghum [*Sorghum bicolor* (L.) Moench]-oat + clover [*Avena sativa* L. interseeded with 80% *Melilotus officinalis* (L.) Lam., 20% *Trifolium pratense*]-corn rotation; and (iii) a 4-yr oat + clover-grain sorghum-soybean-corn rotation. Interactions between crop rotation and N rate were also determined. The study was conducted for 4 yr on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll). Continuous corn produced less grain (5.5 mg ha^{-1} yr^{-1}) than corn grown in rotation (7.6 Mg ha^{-1} yr^{-1} average). Corn following a legume in rotation produced maximum grain yield with 90 kg N ha^{-1}, while continuous corn required at least 180 kg N ha^{-1} for maximum yield. Corn following oat + clover produced maximum yield in a year of above-average precipitation, but this rotation was vulnerable to soil-water deficits. In 3 of 4 yr, corn following soybean in a 4-yr rotation produced more grain than other rotations.

THE EFFECTS of crop rotation on corn yield constitute a large portion of recent rotation research in the USA. Corn is one of the most widely grown crops and is often sensitive to rotation effects. Much research has demonstrated that corn produces more grain when grown in rotation than in continuous monoculture (1,2,3,4,5,10,11,12,16,20,22).

Barber (5), and later Voss and Shrader (21), reported on a long-term study in Iowa in which corn yields declined with increasing frequency of corn in the rotation. Results from Iowa and elsewhere (8,9,11, R.K. Crookston, 1988, personal communication) indicate that the type of crop in the rotation may not be important, as long as corn does not follow itself. Others (1,3,7), however, found corn after legume crops produced more grain than when corn follows nonlegume crops. Corn yield response to rotation is greater in dry or "stress" years than in more favorable environments (5,11,14). Corn response to applied N often varies with previous cropping history (1,2,6,10,11,12,17,19,20). In most cases, response to applied N was greater in continuous monoculture corn or cereal crop-corn cropping systems than when corn followed a legume.

In research reported here, corn response to crop rotation and N was studied as a part of a larger crop rotation experiment. Our objective was to contrast corn yield in three crop rotations with corn yield in continuous monoculture systems, and to evaluate interactions of crop rotation and N rate.

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MATERIALS AND METHODS

The study was located at the University of Nebraska Agricultural Research and Development Center near Mead, NE on a Sharpsburg silty clay loam with an organic matter content of 31 g kg^{-1} in the upper 75 mm.

Corn was grown under rainfed conditions in continuous monoculture (CC) and in three crop rotations: (i) a 2-yr soybean-corn rotation (SOY2); (ii) a 4-yr rotation of oat + clover (80% sweetclover, 20% red clover) -sorghum-soybean-corn (SOY4); and (iii) a 4-yr rotation of soybean-grain sorghum-oat + clover-corn (OAT/CL4). Monoculture plots had been continuously cropped to corn since 1972. Rotation treatments were assigned to main plots in four complete blocks. Corn N subplots were randomly assigned either 0, 90 or 180 kg N ha^{-1} as discussed in an earlier paper (13).

Clover from the previous oat + clover plots was killed with a sweep plow or tandem disk in mid April as weather permitted. Plots were disked twice with a tandem disk in late April or early May, then harrowed just prior to planting. Corn was planted with a six-row planter in the first 10 d of May. Corn hybrid Asgrow Rx717 was planted at a rate of 47 000 viable seeds ha^{-1}. Weeds were controlled with a preemergence application of either alachlor [2-chloro-2,6-diethyl-N-(methoxymethyl)acetanilide] or metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] along with atrazine [2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine], cyanazine [2-[[4-chloro-6-(ethylamino)-S-triazin-2-yl]amino]-2-methylpropionnitrile], and linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] at recommended rates. Corn plots were cultivated the first or second week of June.

Volumetric soil water content was estimated using the neutron scatter technique approximately twice each month in 0 and 180 kg N ha^{-1} subplots. Profile water content was calculated by multiplying the estimates of volumetric water content by their depth increment and summing results.

Aboveground dry matter (DM) samples (1 row by 5 m) were collected in 1984 to 1986 soon after physiological maturity. Ears were removed, stalks were cut at ground level, and samples were weighed separately. A stover subsample (five representative plants) was chopped and used for gravimetric moisture determination. Ears were dried and weighed, with the resulting weight added to the calculated stover weight for total DM. Corn was harvested for grain in early October using a plot combine in 1983 and 1984, and by hand in 1985 and 1986. Harvest area was three rows by 10 m for machine harvest and three rows by 5 m for hand harvest.

Data were analyzed by year and combined for analysis after determining homogeneity of error variances. Orthogonal comparisons were used to partition treatment sums of squares to directly evaluate objectives (18). In cases in which treatment interactions with year involved changes in rank, only analyses by year are discussed. All statistical analyses were performed using the Statistical Analysis System (SAS)(15).

RESULTS AND DISCUSSION

Grain Yield

Significance of *F*-values from analysis of variance of grain yield are shown in Table 1. Both rotation and N rate effects varied with year. Specific interactions will be addressed, but examination of rotation averages across 4 yr is important to estimate yield trends (Table 2). Across years and N rates, corn in CC averaged 5.5, SOY2 averaged 7.0, SOY4 averaged 7.9, and OAT/CL4 averaged 7.7 Mg ha^{-1}. Corn in continuous monoculture produced less yield than the average yield of corn in rotation at each level of applied N. Grain yield of corn in rotation averaged 6.9, 7.9, and 7.9 Mg ha^{-1}, while CC yields were 4.1, 5.6, and 6.8 Mg ha^{-1} at 0, 90, and 180 kg N ha^{-1}, respectively. Corn in 4-yr rotations produced an average of 0.7 Mg ha^{-1} more grain than corn in the 2-yr rotation.

Both rotation × year and N × year interactions involved changes in rank across years, so data were analyzed and presented by year (Table 2). In 1983, yields were low due to lack of precipitation in July (13), which affected corn pollination in all treatments. Neither rotation nor N rate affected corn yields in 1983, except for comparisons between continuous

Table 1. Significance of *F*-values from analysis of variance of corn grain (1983–1986) and dry matter yields (1984–1986) at Mead, NE.

		Grain yield					Dry matter yield			
Source	df	1983	1984	1985	1986	Across years	1984	1985	1986	Across years
Rotation	3	*	*	*	*	*	*	*	*	*
continuous vs. rotation	1	*	*	*	*	*	*	*	*	*
2 yr vs. 4 yr	1	†	*	NS	*	*	*	†	*	*
within 4 yr	1	NS	*	NS	*	NS	*	NS	†	*
Nitrogen	2	NS	*	*	*	*	*	*	*	*
N-rate linear (NLIN)	1	NS	*	*	*	*	*	*	*	*
N-rate quadratic (NQUAD)	1	NS	NS	NS	*	*	NS	NS	*	*
Rotation × N-rate	6	NS	NS	NS	*	*	NS	NS	*	*
continuous vs. rotation × NLIN	1	NS	NS	NS	*	*	NS	†	*	*
continuous vs. rotation × NQUAD	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
2 yr vs. 4 yr × NLIN	1	NS	NS	*	NS	*	NS	NS	NS	NS
2 yr vs. 4 yr × NQUAD	1	NS	NS	*	NS	†	NS	*	NS	NS
within 4 yr × NLIN	1	NS	NS	NS	†	NS	NS	NS	NS	NS
within 4 yr × NQUAD	1	*	NS	NS	*	NS	†	NS	*	*
Year	3(2)‡					*				*
Year × Rotation	9(6)					*				*
Year × N-rate	6(4)					*				*
Year × Rotation × N-rate	18(12)					*				*
CV (%)		17.4	15.1	15.7	8.7	14.0	16.2	14.4	10.0	13.0

†,* Indicates significance at the 0.1 and 0.05 levels, respectively.
‡ Degrees of freedom for dry matter in parentheses.

Table 2. Effect of rotation and N rate on corn grain (1983–1986) and dry matter yields (1984–1986) at Mead, NE.

		Grain yield				Dry matter yield			
		N rate (kg ha^{-1})				N rate (kg ha^{-1})			
Year	Rotation†	0	90	180	Mean	0	90	180	Mean
		Mg ha^{-1}				Mg ha^{-1}			
	CC	3.8	3.8	4.1	3.9				
1983	SOY2	5.0	5.7	5.2	5.3				
	SOY4	6.7	6.1	6.9	6.6				
	OAT/CL4	5.6	6.8	5.4	5.9				
	Mean:	5.3	5.6	5.4	5.4				
	CC	2.1	3.0	3.9	3.0	6.2	7.4	8.2	7.3
1984	SOY2	4.5	5.5	6.1	5.3	8.7	10.6	8.6	9.3
	SOY4	6.1	6.7	6.8	6.5	11.7	13.0	12.4	12.4
	OAT/CL4	5.7	5.5	6.1	5.7	8.8	8.6	11.1	9.5
	Mean:	4.6	5.2	5.7	5.2	8.9	9.9	10.1	9.6
	CC	6.4	7.3	9.2	7.6	9.8	12.7	14.5	12.4
1985	SOY2	6.7	9.9	9.4	8.7	20.4	16.1	14.9	17.1
	SOY4	8.5	9.1	9.2	8.9	16.1	15.8	17.4	16.4
	OAT/CL4	7.9	8.9	9.2	8.7	14.4	14.9	16.0	15.1
	Mean:	7.4	8.8	9.2	8.4	15.2	14.9	15.7	15.3
	CC	4.0	8.2	10.0	7.4	7.6	11.8	16.2	11.9
1986	SOY2	7.7	9.6	9.8	9.1	12.1	14.0	15.0	13.7
	SOY4	8.4	10.6	10.2	9.7	13.5	17.8	16.1	15.8
	OAT/CL4	10.4	10.4	10.7	10.5	16.8	16.9	17.6	17.1
	Mean:	7.6	9.7	10.1	9.2	12.5	15.1	16.2	14.6
	CC	4.1	5.6	6.8	5.5	7.9	10.6	13.0	10.5
Mean	SOY2	6.0	7.7	7.6	7.1	13.7	13.6	12.8	13.4
	SOY4	7.4	8.1	8.3	7.9	13.8	15.5	15.3	14.9
	OAT/CL4	7.4	7.9	7.8	7.7	13.3	13.5	14.9	13.9
	Mean:	6.2	7.3	7.6	7.0	12.2	13.3	14.0	13.2

† CC = Corn grown in continuous monoculture, SOY2 = 2-yr soybean-corn rotation, SOY4 = 4-yr oat + clover-sorghum-soybean-corn rotation, and OAT/CL4 = 4-yr soybean-grain sorghum-oat + clover-corn rotation.

corn (3.9 Mg ha^{-1}) and the mean of all rotations (5.9 Mg ha^{-1}), and the within 4-yr × N rate quadratic comparison. Application of 90 kg N ha^{-1} increased corn yield in SOY4, but inexplicably decreased yield of corn in OAT/CL4 (Table 2).

Rotation affected corn yield in 1984. All single degree of freedom comparisons using rotation sums of squares were significant (Table 1). Continuous corn receiving 180 kg N ha^{-1} produced less yield than any other rotation treatment (Table 2). Corn in SOY2 produced less grain than the mean of the SOY4 and OAT/CL4 rotations. More corn grain was produced by SOY4 than OAT/CL4, likely due to vigorous clover growth prior to corn planting. Spring weather conditions in 1984 delayed initial tillage until 18 April when clover was 0.4- to 0.5-m tall. Precipitation was plentiful in June of 1984, but less so for July and August (13). Soil-water content differences were nonsignificant, but corn in OAT/CL4 consistently ranked lowest in soil water content in the latter one-half of the growing season (Fig. 1). Corn yield in OAT/CL4 was reduced relative to SOY4. We suspect it was due to water deficiency in the latter periods of the growing season (Fig. 1). Grain yield increased linearly with added N in 1984 and the effect was consistent across rotations (Table 1 and 2).

In 1985, yield was affected by rotation and N rate (Table 1 and 2). Continuous corn produced less grain than corn in rotation, and corn yields did not differ among the rotations. Applications of N affected corn yield, and the effect was characterized by a linear model (Table 1 and 2). Response of corn to applied N in the SOY2 rotation differed from that of 4-yr rotations. Yield of corn in the SOY2 rotation increased with the first increment of applied N and inexplicably decreased with the second, while corn in both 4-yr rotations increased with both increments of added N (Table 2).

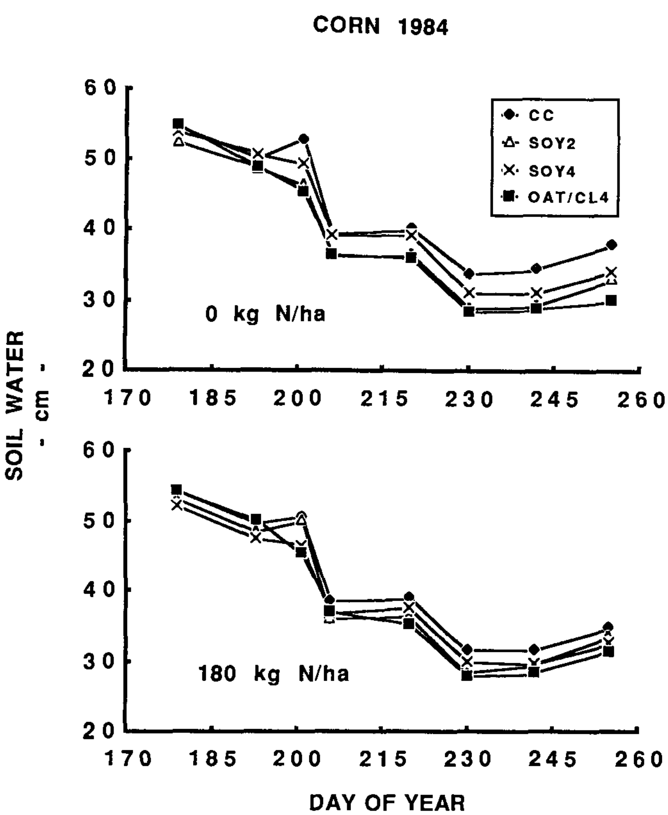

Fig. 1. Soil water content in the 0- to 1.5-m profile in 1984. CC = Corn grown under rainfed conditions in continuous monoculture, SOY2 = 2-yr soybean-corn rotation, SOY4 = 4-yr oat + clover-sorghum-soybean-corn rotation, and OAT/CL4 = 4-yr soybean-grain sorghum-oat + clover-corn rotation.

In 1986, the effects of rotation varied with N rate and the interaction involved changes in rank among treatment means (Table 1). Corn in OAT/CL4 produced the highest grain yield of all treatments and yield was not affected by additions of N fertilizer (Table 2). Clover residue production from the previous OAT/CL4 treatment averaged 2.0 Mg ha^{-1} DM prior to initial tillage. Precipitation (13) was adequate for both corn growth and rapid microbial decomposition of clover residues. Nitrogen from symbiotic fixation along with N mineralized from clover residues supplied sufficient N for maximum grain yield. Corn yield response to applied N was quite similar for the two rotations following soybean. Both SOY2 and SOY4 showed a large increase, with 90 kg N ha^{-1}, and little additional response to the second increment of N applied. Grain yield of CC increased linearly with applied N; the N response of CC was greater than the N response of corn in rotation (Table 2).

Yield increase due to rotation ([mean rotation yield/monoculture yield] × 100%) was 152, 194, 115, and 129% for 1983 to 1986, respectively. Rotation yield increases over CC were more pronounced in 1983 and 1984, years with below-normal, July and August precipitation (13). This agrees with other research in that corn yield response to rotation is increased in "dry" or "stress" years (5,11,14).

A consistent yield advantage of corn in SOY4 over corn in SOY2 was noted. Differences may be due to improved soil physical properties (water holding capacity or aggregate stability) or greater N-mineralization potential in the 4-yr rotation, which included oat + clover. We continue to investigate these possibilities. Another explanation for yield differences between 2- and 4-yr rotations is the reduced frequency of corn in the 4-yr rotations (8,9,11, and R.K. Crookston, 1988, personal communication). If monoculture yields were limited by deleterious organisms or subclinical pathogens specific to corn, perhaps excluding corn for three consecutive years controlled populations of these organisms.

Total Dry Matter

Treatment effects on total above-ground DM at physiological maturity nearly paralleled the effects on grain yield (Table 2). As with grain yield, DM was affected by rotation and N rate, but the effects were not consistent across years. In 1984, response of DM to rotation and N rate were identical to grain yield effects. The discussion of grain yield effects is generally appropriate for the explanation of DM effects, thus only differences between the two response variables will be discussed.

Differences between SOY2 and the average of 4-yr rotations were more pronounced for DM than for grain yield in 1985 (Table 1 and 2). Grain and DM yield of corn in SOY2 increased with the first increment of applied N and declined with the second increment. Mean response of corn DM in 4-yr rotations was not affected by application of 90 kg N ha^{-1}, but did increase with application of 180 kg N ha^{-1}. It is difficult to explain the grain yield and DM decrease for SOY2 resulting from the second increment of applied N. The possibility of high soil-N levels for this treatment were suspected because 1983 and 1984 crop yields were below average, but soil NO_3-N data from samples taken in the fall of 1984 did not confirm this (data not shown).

In 1986, differences between the 4-yr rotations were less pronounced for DM than for grain yield. Corn DM in OAT/CL4 did not respond to N rate, while DM in SOY4 increased sharply with the first increment of applied N, and declined with the second level.

Water Use

Water content was monitored in three of the four replications throughout the 1984 to 1986 growing seasons. Water content in the 0- to 1.5-m profile in corn plots did not differ within rotation or N treatment at any time. In 1984, water depletion did occur (Fig. 1) but differences between treatments were nonsignificant. In 1985 and 1986, precipitation was above normal (13) and appreciable water depletion did not occur (data not shown).

Grain and Plant Moisture, Grain Density, and Seed Size

The effect of rotation on grain moisture at harvest varied with year, but differences were small and not agronomically significant (data not shown). Moisture content of whole plants at maturity was affected by rotation in 1984 and 1986, but not in 1985. Results were not consistent across years, except CC had higher whole-plant moisture (average 590 g kg^{-1}) than corn in rotation (520 g kg^{-1}), which suggests crop development on the CC plots lagged behind corn in rotation.

Grain density was measured in 1983 and 1984, and seed size was measured in 1985. Treatment effects were due to differences between grain from CC and corn grown in rotation. Grain from CC plots was less dense than corn grown in rotation (679 kg m^{-3} vs. 697 kg m^{-3}). Continuous corn produced smaller seed in 1985 (3.13 g $seed^{-1}$) than corn in rotation (3.38 g $seed^{-1}$).

CONCLUSIONS

Continuous corn produced less grain and DM than did corn grown in rotation. In a year of above-normal precipitation, corn in OAT/CL4 produced more grain than in any of the other cropping systems. However, the benefits of including clover in a rotation must be weighed against its potential to deplete soil water. In 3 of the 4-yr, corn in SOY4 produced more grain than corn in any of the other rotations. Corn grown in rotation required less fertilizer N than continuous corn for maximum yield.

REFERENCES

1. Adams, W.E., H.D. Morris, and R.N. Dawson. 1970. Effect of cropping systems and nitrogen levels on corn (*Zea mays* L.) in the Southern Piedmont Region. Agron. J. 62:655–659.
2. Baldock, J.O., R.L. Higgs, W.H. Paulson, J.A. Jackobs, and W.D. Shrader. 1981. Legume and mineral N effects on crop yields in several crop sequences in the Upper Mississippi Valley. Agron. J. 73:885–890.
3. Baldock, J.O., and R.B. Musgrave. 1980a. Manure and mineral fertilizer effects in continuous and rotational crop sequences in Central New York. Agron. J. 72:511–518.
4. Baldock, J.O., and R.B. Musgrave. 1980b. The Aurora rotation study. A statistical and agronomic analysis of the crop yields and their variability. Search Agric. 8:1–15.
5. Barber, S.A. 1972. Relation of weather to the influence of hay crops on subsequent corn yields on a Chalmers silt loam. Agron. J. 64:8–10.
6. Bartholomew, W.V., W.D. Shrader, and A.J. Englehorn. 1957. Nitrogen changes attending various crop rotations on Clarion-Webster soils in Iowa. Agron. J. 49:415–418.
7. Bolton, E.F., V.A. Dirks, and W.I. Findlay. 1979. Some relationships between soil porosity, leaf nutrient composition and yield for certain corn rotations at two fertility levels on Brookston clay. Can. J. Soil Sci. 59:1–9.
8. Cook, R.J. 1984. Root health: importance and relationship to farming practices. p. 111-127. *In* D.F. Bezdicek, J.F. Power, D.R. Keeney, and M.J. Wright (ed.) Organic farming: current technology and its role in a sustainable agriculture. Spec. Publ. 46. ASA, CSSA, and SSSA, Madison, WI.
9. Cook. R.J. 1986. Interrelationships of plant health and the sustainability of agriculture, with special reference to plant diseases. Am. J. Altern. Agric. 1:19–25, 28.
10. Heichel, G.H., and D.K. Barnes. 1984. Opportunities for meeting crop nitrogen needs from symbiotic nitrogen fixation. p. 49-59. *In* D.F. Bezdicek, J.F. Power, D.R. Keeney, and M.J. Wright (ed.) Organic farming: current technology and its role in a sustainable agriculture. Spec. Publ. 46. ASA, CSSA, and SSSA, Madison, WI.
11. Langer, D.K., and G.W. Randall. 1981. Corn production as influenced by previous crop and N rate. p. 182. *In* Agronomy abstracts. ASA, Madison, WI.
12. Nafziger, E.D., R.L. Mulvaney, D.L. Mulvaney, and L.E. Paul. 1984. Effect of previous crop on the response of corn to fertilizer nitrogen. J. Fert. Issues. 1:136–138.
13. Peterson, T.A., and G.E. Varvel. 1989a. Crop yield as affected by crop rotation and N rate. I. Soybean. Agron. J. 81:727–731 (this issue).
14. Sahs, W.W., and G. Lesoing. 1985. Crop rotations and manure versus agricultural chemicals in dryland grain production. J. Soil Water Conserv. 41:511–516.
15. SAS Institute. 1982. SAS user's guide: Statistics. SAS Institute, Cary, NC.
16. Shaw, R.H., K. Ross, and C. Meyers. 1980. Evaluation of the management, yield, and water-use interactions on corn in Northwestern Iowa. Iowa State J. Res. 55:119–126.
17. Shrader, W.D., W.A. Fuller, and F.B. Cady. 1966. Estimation of a common nitrogen response function for corn (*Zea mays*) in different crop rotations. Agron. J. 58:397–401.
18. Steel, R.G., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill Book Co., New York.
19. Stickler, F.C., W.D. Shrader, and I.J. Johnson. 1959. Comparative value of legume and fertilizer nitrogen for corn production. Agron. J. 51:157–159.
20. Voss, R.D., and W.D. Shrader. 1979. Crop rotations: effect on yields and response to nitrogen. Iowa State Univ. Coop. Ext. Serv. Pm-905.
21. Voss, R.D., and W.D. Shrader. 1984. Rotation effects and legume sources of nitrogen for corn. p. 61-68. *In* D.F. Bezdicek, J.F. Power, D.R. Keeney, and M.J. Wright (ed.) Organic farming: current technology and its role in a sustainable agriculture. Spec. Publ. 46. ASA, CSSA, and SSSA, Madison, WI.
22. Welch, L.F. 1979. Nitrogen use and behavior in crop production. Univ. of Illinois, Agric. Exp. Stn. Bull. 761.