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M. M. Harbur
Iowa State University

M. Ghaffarzadeh
Iowa State Universtiy

R. M. Cruse
Iowa State University, rmc@iastate.edu

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Corn (*Zea mays* L.) Yield Response to Nitrogen Fertilizer in Conventional and Alternative Rotations

M.M. HARBUR, M. GHAFFARZADEH, AND R.M. CRUSE

Department of Agronomy, Iowa State University, Ames, IA 50011
mmharbur@iastate.edu

Nitrogen (N) fertilization recommendations are not available for corn in rotation with small grains or forages despite the possibility that the N response may differ from that of more conventional corn-soybean rotations. Rotations of corn with soybean (CS), corn with soybean and oat (CSO) and corn with soybean and an oat/berseem clover intercrop (CSOB) were established in 1991 and studied from 1993 through 1998 to determine the optimal N fertilization level for corn produced in each rotation. Corn in each rotation received NH_4NO_3 applied at the rates of 0, 56, 112, or 168 kg N ha^{-1}. Significant differences in corn grain yield occurred between rotations in three years, but no rotation was consistently superior. Corn grain yield increased with N fertilizer in each year, but in 3 of 6 years there was no advantage to applying N at a rate greater than 112 kg ha^{-1}. No difference in N response between rotations was observed:

INDEX DESCRIPTORS: corn, soybean, oat, berseem clover, rotation, nitrogen.

The potential to increase yields through crop rotations has been well established. Rotations can contribute to soil fertility (Copeland 1992), aggregation, water infiltration (McVay et al. 1989), and water holding capacity by increasing soil organic matter. Rotations can also improve soil quality when less erosive crops such as small grains and legumes are included (Dick and Van Doren 1985; Griffith et al. 1988). Pest cycles, including weeds, insects, and disease may also be broken by rotation (Francis and Clegg 1990). Research in Minnesota suggests that adding a third crop between corn and soybean [*Glycine max* (L.) Merr.] would create a cropping system superior to corn-soybean alone, particularly from the yield standpoint (Crookston et al. 1991).

Small grains are a favorable candidate for a three-crop rotation, but are unpopular in Iowa because of low market value and high yield variability. Esteem for small grains, however, may increase if they are intercropped with a forage legume. Such forage legumes may either be used as livestock feed and/or to contribute N to succeeding crops. Legume cover crops can contribute from 67 to 134 kg N ha^{-1} to the succeeding crops; in northern climates, approximately 101 kg N ha^{-1} can be contributed to the succeeding corn crop by legumes intercropped with small grains (Bruulsema and Christie 1987).

Traditional grass legume combinations include oat (*Avena sativa* L.) underseeded with alfalfa (*Medicago sativa* L.) or mammoth red clover (*Trifolium pratense* L.), or rye (*Secale cereale* L.) or oat underseeded with hairy vetch (*Vicia villosa* Roth subsp. *villosa*). However, preventing legume regrowth in the following corn crop is a major challenge. Surviving legumes may deplete soil moisture to the detriment of corn yield (Ebelhar et al. 1984; Hesterman et al. 1986; Frye et al. 1988; Badaruddin and Meyer 1989). One potential solution to this challenge is berseem clover.

Berseem clover (*Trifolium alexandrinum* L.), also known as Egyptian clover, is a true annual that winterkills in Iowa. It responds well to multiple cuttings and produces high quality forage. Berseem produces as much as as 10 Mg dry matter ha^{-1} yr^{-1} (Singh et al. 1989). Berseem may be left to contribute N to the succeeding crop or to meet livestock needs in the event that the intercropped small grain produces low yield. As livestock feed, berseem may be harvested as hay, made into silage, or grazed. Grazing studies of berseem have shown no cases of bloat in ruminants (Baldridge et al. 1993; Sims 1991.).

Corn yield response suggests that berseem contributes about 44 kg N ha^{-1} to the following corn crop (Ghafffarzadeh 1997). It is unclear, however, how much of the corn yield increase is due to berseem N contribution and how much may be due to improvements in soil quality, decreases in pest pressure, or other rotation effects (Bullock 1992). It has been suggested that the amount of N contributed by legumes may be overestimated by as much as 123% (Hesterman et al. 1986). Therefore, traditional corn N response curves to fertilizer cannot be used to determine how to manage soil fertility when berseem clover is included in the rotation. A new N response curve may be necessary to determine how much additional N must be added to optimize corn yield.

The objectives of this experiment were to evaluate corn yield potentials in a conventional corn-soybean rotation and in corn-soybean-oat rotations with and without berseem clover and to determine the optimum fertilizer rate to be used with corn following berseem clover.

METHODS

Plots

Research was conducted from 1993 to 1998 near Nashua, IA. Soil was predominantly Kenyon (fine-loamy, mixed, mesic Typic Hapludoll) series with 0–5% slope. Treatments included a two year rotation of corn-soybean (CS); and three-year rotations of corn-soybean-oat (CSO) and corn-soybean-oat/berseem clover (CSOB). Rotations were established in 1991.

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Table 1. **Total precipitation data from Nashua, IA (NOAA-NCDC, 1993–1998).**

	YEAR						
MONTH	1993	1994	1995	1996	1997	1998	MEAN
	Precipitation (mm)						
April	61.0	29.0	101.8	**	78.3	65.6	67.1
May	54.0	38.0	61.7	64.6	74.2	113.2	67.6
June	138.0	29.0	172.2	99.0	157.0	203.1	133.1
July	331.9	83.0	140.0	33.0	122.0	30.1	123.3
August	252.6	35.0	147.0	90.0	123.0	170.0	136.3
September	38.5	37.0	59.0	67.0	97.0	44.9	57.2
October	0.0	49.0	43.9	**	202.0	164.2	91.8
Total	876.0	300.0	725.6	**	853.5	791.1	676.5

**data missing

Crop strips were 4.6 m wide and 60 m long. Corn and soybean were spaced in six rows 0.76 m apart; oats were drilled in 24 rows spaced 0.19 m apart. Seeding rates (ha^{-1}) were: 60,000 corn, 395,000 soybean; 134 kg oat in the CSO rotation; 134 kg oat and 16.8 kg berseem were used in CSOB.

All crop components of a rotation treatment were grown in separate but adjacent strips each year. This allowed the collection of corn N response data each year. Corn followed soybean in the CS treatment, corn followed oat in the CSO treatment and corn followed the oat/berseem intercrop in the CSOB treatment. Treatments were arranged in a randomized complete block design with each treatment replicated once per block. There were four blocks.

Corn main plots were divided into four 15 m long subplots. Each subplot received a different (0, 56, 112, or 168 kg ha^{-1}) nitrogen rate, hand-applied as inorganic fertilizer prior to cultivation. Nitrogen was applied as NH_4NO_3 in all years. Phosphorus and potassium were not applied to any crops because of high soil tests for both nutrients.

Pre-emergence weed control was accomplished by banding granule alachlor ("Lasso") at planting. Corn and soybean were cultivated two to three times per season. In late August 1993, oat plots in the CSO rotation were tilled in order to control weeds after grain harvest.

Corn yield measurements were harvested from the center two rows of the six row strip and from the center 12.2 m of each subplot using a small-plot combine. Grain yields were adjusted to 15.5 and 13% grain moisture for corn and soybeans, respectively.

Statistics

A split-plot analysis of variance (ANOVA) was used to interpret effect. The linear additive model used to describe the effects was:

$$Y_{ijkl} = \mu + A_i + B_{(i)j} + R_k + AR_{ik} + BR_{(i)jk} + N_l + AN_{il} + BN_{(i)jl} + RN_{kl} + ARN_{ikl} + BRN_{(i)jkl}$$

where A is the effect of years, B is the effect of blocks, R is the effect of rotation, and N is the effect of N rate. Years and blocks were considered to be random effects, while rotation and N rate were considered to be fixed effects. Effects were considered significant when the probability of a larger F-value was $P<0.05$.

RESULTS

Weather

Temperature and precipitation data were collected at the research station. Note that precipitation was greater than normal in 1993 and 1997 and below normal in 1994 and 1996 (Table 1). Average monthly temperatures during 1993 were cooler than normal (Table 2). All plots were destroyed by hail in 1995, and, therefore, no yield data are shown for that year.

Table 2. **Mean temperature data from Nashua, IA (NOAA-NCDC, 1993–1998).**

	YEAR						
MONTH	1993	1994	1995	1996	1997	1998	MEAN
	Temperature (°C)						
April	6.4	8.4	6.2	**	6.5	9.9	14.0
May	14.5	15.6	13.6	12.1	11.9	16.2	14.0
June	19.3	22.2	21.1	19.8	21.2	19.4	20.5
July	18.6	22.7	22.3	20.4	21.4	21.3	21.1
August	11.0	20.1	23.6	19.9	19.6	22.3	19.4
September	9.1	18.6	14.9	15.9	16.9	19.2	15.8
October	6.6	11.3	9.1	**	10.4	10.8	9.6
Mean	12.2	17.0	15.8	17.6	15.4	17.0	17.0

**data missing

Rotation Effect

There was a significant interaction between year and rotation, and so it was necessary to analyze each year separately. There was no significant interaction between rotation and N rate, and so the results presented for rotation are averaged across all levels of N.

Significant rotation effects occurred in three of the five years studied (Table 3). No single rotation, however, proved to be superior over the five years of the study. This is surprising, given the work of Ghaffarzadeh (1997), which included the first three years of this study and suggested that the CSOB rotation provided a significant 10% corn yield advantage over a CSO rotation.

Fertilizer N

Because there was no significant yield increase (and hence, little N contribution) by the CSOB rotation, there was also no significant interaction noticed between rotation and N effect. Each year was analyzed separately, however, so as to better relate the N effect to the previously-discussed rotation effect. As mentioned previously, there was no significant rotation*N effect, and so the N effect was averaged across all rotations.

Table 3. Annual corn grain yield (Mg ha^{-1}) by rotation and year. All plots were destroyed by hail in 1995 so data are not shown. Rotations are: corn-soybean (CS), corn-soybean-oat (CSO) and corn-soybean-oat/berseem (CSOB).

ROTATION	YEAR 1993[a]	1994[a]	1996[a]	1997	1998	ALL
CS	3.38	6.66	9.99	7.72	7.95	7.64
CSO	4.35	8.26	8.67	6.97	7.27	7.82
CSOB	6.28	6.62	8.90	7.67	8.25	8.34
Mean	4.67	7.18	9.19	7.46	7.83	7.93
$LSD_{0.05}$	1.29	1.20	1.26	1.21	1.54	1.21

[a]Rotation effect significant at $P < 0.05$ level of probability

Table 4. Annual corn grain yield (Mg ha^{-1}) by fertilizer N rate and year. Yields are averaged across the three rotations (corn-soybean, corn-soybean-oat and corn-soybean-oat/berseem).

KG N HA^{-1}	YEAR 93	94	96	97	98	ALL
0	2.96	4.77	6.90	4.09	5.42	4.83
56	4.13	6.92	8.72	6.23	6.53	6.51
112	5.47	8.20	10.35	8.50	9.12	8.33
168	6.13	8.84	10.78	9.39	10.32	9.46
mean	4.67	7.18	9.19	7.05	7.85	7.38
linear fit	**	**	**	**	**	**

**Significant at $P = 0.01$ level of probability; NS, not significant at $P < 0.05$

N rate, as anticipated, had a significant effect on corn grain yield in every year (Table 4). In each case, yield generally increased with N rate. In three of the five years, however, there was little advantage to applying N at the rate of 168 kg ha^{-1} rather than at the rate of 112 kg ha^{-1} (Figure 1).

DISCUSSION

We suspect that there are three explanations for the difference in results between our study and that of Ghafffarzadeh (1997). First, one must consider the variability of the berseem contribution to corn yield. McVay et al. (1989) found that yield benefit of berseem to a following crop (expressed as the amount of synthetic N fertilizer required to realize the same yield) ranged from 16 to 97 kg ha^{-1} over the three years of their study. This variability is typically related to the relative success in establishing the berseem stand.

Secondly, some of the N fixed by berseem will be sequestered or displaced by the concurrent small grain crop (Holderbaum et al. 1990). In the case of our study, the presence of oat may have reduced the net N contribution to the following corn crop.

Thirdly, it seems that the advantage of berseem may be most strongly recognized in years of adverse weather. In dry years, berseem (or any other cover crop, for that matter) may help to conserve moisture, similar to that observed by Myers and Wagger (1991) with crimson clover. In very wet years, the more gradually-released N from berseem residue may be less prone to early-season leaching during heavy rain than synthetic-fertilizer N which is often applied entirely at the beginning of the growing season.

We found the results of this study to very surprising given the

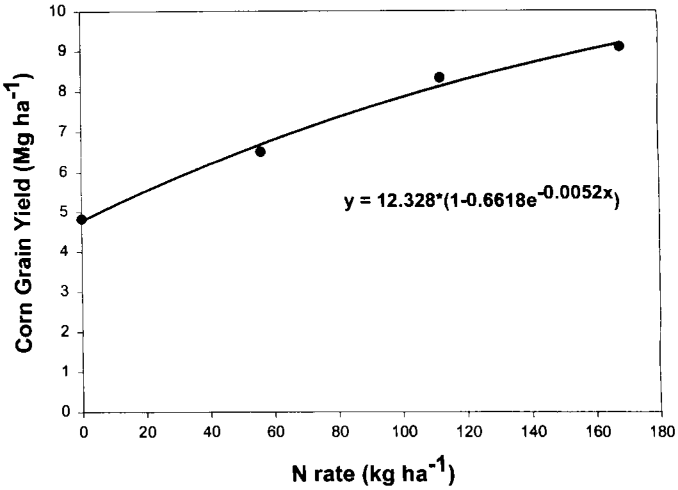

Fig. 1. Mean corn grain yield response to fertilizer N. Response is averaged across rotations. Response was fit with monomolecular function.

studies discussed in the introduction to this article which attribute yield advantages to the use of longer rotations. We suspect that the same general soil which has allowed Iowa farmers to succeed for a quarter century with a minimal rotation (corn-soybean) may also have responded less to the potential soil fertility and structure benefits offered by longer rotations. It also is important to note that other legumes, including hairy vetch and crimson clover, have offered greater corn yield benefits than berseem clover (McVay et al. 1989).

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