Response Of Sugarbeet To Applied Nitrogen Following Field Bean (*Phaseolus vulgaris* L.) And Corn (*Zea mays* L.)

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ABSTRACT

Preliminary results showed lower root and sucrose yield for sugarbeet following corn than following field bean and that N rates may need to be increased following corn. This study was conducted to evaluate N needs for sugarbeet following corn and field bean in three-year rotations of corn-corn-sugarbeet compared to corn-field bean-sugarbeet. As a result of slower early to mid-season growth, yield of roots was less following corn than following field bean regardless of N rate applied. Regression of relative yield against N rate allowed calculation of N rate associated with varying yield goals (%) of both yield parameters. Approximately 100 kg ha^{-1} more N was required to reach a particular yield goal for either roots or recoverable sucrose following corn as compared to following field bean. For a given yield goal, 40 kg ha^{-1} more N was required if the goal was to produce roots as compared to sucrose production. Differences in yield of roots following the two crops could not be explained by differences in soil structure, soil N or carry-over soil moisture.

Additional Key Words: Fertilizer nitrogen, rotation, cropping system

Rotations play an important role in sugarbeet production and influence the amount of N needed for optimum sucrose yield. Crop rotations are recommended for the management of soil borne diseases such as *Aphanomyces* and *Rhizoctonia* among others (Duffus and Ruppel, 1993). Management of immobile pests such as nematodes and insects with at least one life cycle stage restricted to the soil is often accomplished with the aide of rotations (Cooke, 1993). A long term study conducted in Michigan showed that inclusion of forage legumes in rotations increased yields of all crops including sugarbeet, due to the N supplied (Robertson, Cook and Davis, 1976) and improvement of soil structure (Robertson, 1952).

Inadequate N will limit plant growth and root yields, but over fertilization reduces recoverable sucrose (Hills and Ulrich, 1971). Consequently, adjusting N rates is imperative to optimize sucrose production. General N recommendations are useful, but may need to be adjusted when the specific rotation and crop sequence are considered.

In 1972, a cropping system (rotation) study was initiated in Michigan to evaluate the quantity of residues needed to be returned to the soil and how often sugarbeet could be grown in rotation. Corn was used to vary the amount of crop residues returned to the soil. A complete description of the study and summarization of yield results are reported elsewhere (Christenson, Bricker and Gallagher, 1991). An economic analysis of the production from the various cropping systems showed that sugarbeet was a major component of adjusted gross return (Christenson et al., 1995). For example, in the three and four year rotations, the value of sugarbeet averaged five times that of corn and 2.5 times that of field bean. In a four-year rotation, sugarbeet return was 5.6 times that of oat or alfalfa. These data suggested that growers would choose to shorten rotations to include sugarbeet more frequently.

This economic advantage occurred even though the long-term sugarbeet yield was 3.8 Mg ha^{-1} less following corn than following field bean. The current studies were initiated with the goal of evaluating the role of N fertilization in overcoming this yield difference. The specific objectives of this work were to 1) measure the effect of corn or field bean as a previous crop on yield response of sugarbeet to applied N, 2) evaluate some of the causes for the difference in yield and 3) determine the optimum N rate for sugarbeet following corn and field bean.

MATERIALS AND METHODS

Field Studies.

These studies were conducted on a Misteguay silty clay [Aeric Endoaquents, fine mixed (calcareous), mesic] and characterization data are given in Table 1. This soil is fine textured and tests high in extractable K, Ca and Mg. Extractable P reflects prior fertilization and the pH was in the alkaline range. At this soil test K concentration no fertilizer K was recommended and none was applied. This soil was representative of the finer textured soils in the sugarbeet production area of Michigan.

Table 1. Cation exchange capacity, pH, extractable nutrients†, particle size distribution and field capacity data for the Misteguay silty clay soil and precipitation from October through March prior to each growing season and April - September of the growing season for N rate on sugar beet study conducted from 1992-1997.

Soil Characterization			Precipitation (cm)			
Factor	Unit	Value	Year	Oct-Mar	Year	Apr-Sep
CEC	cmol(+) kg^{-1}	29.0	1990-91	47	1991	55
pH	-	7.8	1991-92	28	1992	48
P	g kg^{-1}	42	1992-93	34	1993	47
K	g kg^{-1}	210	1993-94	21	1994	51
Ca	g kg^{-1}	4952	1994-1995	28	1995	31
Mg	g kg^{-1}	444	1995-96	24	1996	48
			1996-97	35	1997	36
Particle Size Distribution (g kg^{-1})			Field Capacity (cm cm^{-1})			
Sand	Silt	Clay				
150	390	460	0.10-0.15			

† Bray and Kurtz P_1 extractable P and ammonium acetate extractable cations.

Sugarbeet plots in the cropping systems study described above were split and four N rates (0, 45, 90 and 135 kg N ha^{-1}) were applied. Data from a three-year study comparing the effect of N rate on yield and quality of sugarbeet from the corn-field bean-sugarbeet and the corn-corn-sugarbeet rotations were selected for the current paper.

Results from the cropping systems study suggested the need to evaluate a larger set of N rates, but due to space limitations could not be superimposed in that study. Consequently, three additional experimental areas were established so sugarbeet could be grown in the third year of the two rotations being studied. Corn and field bean in these rotations received an application of 150 and 45 kg N ha^{-1}, respectively. N rates applied to sugarbeet were 0, 34, 67, 101, 135, 168, 202 and 235 kg N ha^{-1}. This study was conducted in 1994, 1995 and 1997. The study in 1996 was abandoned due to deer damage.

In both studies, N was broadcast prior to spring tillage and tilled into the soil with a field cultivator equipped with curved tines and rolling baskets. Experimental units measured 2.84 x 10.1 m in the cropping systems study and 2.84 x 20.2 m in the second study. Planting time fertilizer in both studies consisted of 55 kg P_2O_5 ha^{-1} placed to the side and below the seed. Herbicides applied are listed in Table 2. All crops were grown in

Table 2. Herbicides applied for weed control for the N on sugarbeet study from 1991 - 1997.

Crop	Years	Herbicide	Rate
			kg ha^{-1} a.i.
Corn	1991-1996	cyanazine	2.0
		metolachlor	2.2
Field Bean	1991-1993	metolachlor	2.2
		chloramben	2.2
	1994-1995	metolachlor	2.2
		EPTC	2.5
	1996	dimethenamid	1.3
		EPTC	2.5
Sugarbeet	1992-1996	pyrazon	3.4
		ethofumesate	1.7
		diethalyl ethyl	2.2
	1997	pyrazon	3.4
		ethofumesate	1.7

71 cm rows. Sugarbeet seeds were planted at a 5 cm spacing and hand thinned in June to 20 cm between plants. Detailed procedures used in the cropping systems study (Christenson, Bricker and Gallagher, 1991) were followed in the second study also. 'Mono-Hy E-4' sugarbeet hybrid was grown in all years except the last year of the second study when 'Mono-Hy E-17' was grown.

The average October - March precipitation was 31 cm (ranged from 21 - 47 cm) and from April - September precipitation was 45 cm (ranged from 31 - 55 cm) (Table 1). Water holding capacity of the soil is 14 cm to a depth of 90 cm.

Leaf area measurements were made in both field studies three times between 10 and 16 weeks after planting. At each sampling, four contiguous-evenly spaced plants were hand dug, the leaves removed and leaf area determined utilizing a leaf area meter. Area occupied by the plants was determined to facilitate the calculation of LAI. At harvest a sample of twenty roots was selected from each experimental unit for processing and measurement of sucrose and clear juice purity.

Laboratory Studies.

Procedures utilized by the Michigan Sugar Company Agricultural Research Laboratory adapted from Carruthers and Oldfield (1961), and Dexter, Frakes and Snyder (1967) were followed to measure sucrose and clear juice purity.

Soil samples were taken in the spring of 1992 and 1993 from the cropping systems study to measure mineral N, indices of N availability and oxidizable C. Twenty cores, 2 cm in diameter and 22 cm deep, were composited from each experimental unit. The samples were air dried, ground and saved for analysis. Procedures used were: KCl extractable mineral N (Maynard and Kalra, 1993); phosphate-borate extractable N (Giannello and Bremner, 1986, 1988); anaerobic mineralizable N (Waring and Bremner, 1968); autoclave released N (Stanford and Demar, 1969), alkaline permanganate extractable N (Subbiah and Asija, 1956), mineralization potential (Christenson and Butt, 1997) and oxidizable C (Allison, 1965).

Statistical Analysis.

Both field studies were placed in a randomized complete block design with a split plot with four replications. The main plot was previous crop and N rates were the subplots. Different sets of experimental units were used each year in the cropping systems study and individual experimental areas were used in the second study. Yield and quality data were analyzed as a split plot combined over years. A Fishers protected LSD was used to test differences between means. In both studies, the previous crop by nitrogen rate interaction was significant, but the year by nitrogen by previous crop was not. Leaf area index (LAI) data were analyzed on an annual basis as a split plot and soil analyses means were separated utilizing the *t* test.

RESULTS

The cropping systems study had been in place for 20 years when the N rate study was started. Yield of roots following both crops was increased by each N rate up to 135 kg ha^{-1} (Table 3). Yield following corn

Table 3. Effect of previous crop and nitrogen rate on yield of root, percent sucrose and recoverable white sucrose (RWS) from a long term cropping systems study, 1992-1994.

Nitrogen Rate	Root Yield following		Sucrose following		RWS following	
	F. Bean	Corn	F. Bean	Corn	F. Bean	Corn
kg ha^{-1}	- - Mg ha^{-1} - -		- - g kg^{-1} - -		- - Mg ha^{-1} - -	
0	56.1	40.2	182	178	7.59	5.27
45	59.1	50.6	182	179	7.84	6.71
90	63.4	56.1	180	181	8.27	7.47
135	68.9	64.3	179	180	9.02	8.45
LSD (5%)	3.7		2		0.47	

was less than following field bean at all N rates. After field bean, sucrose concentration was suppressed below the control at both 90 and 135 kg N while following corn sucrose was increased over the control at both 90 and 135 kg N following corn.

Recoverable sucrose was calculated taking into account sucrose concentration, clear juice purity and yield. Recoverable sucrose yield was increased up to 135 kg N following both crops. Yield of recoverable sucrose was also greater following field bean than corn at all N rates.

Since insufficient space was available for additional N rates in the cropping systems study, a separate study was initiated in order to accommodate additional N rates. Two rotations were established; one was corn-field bean-sugarbeet and the second was corn-corn-sugarbeet. Establishment of the rotations was managed so that sugarbeet could be grown in the third year of both rotations. This study was also conducted for three years.

Similar to the cropping systems study, yield of roots and recoverable sucrose was greater following field bean than following corn (Table 4). Root yield was not increased at N rates above 168 kg N ha^{-1} following

Table 4. Effect of previous crop and nitrogen rate on yield of root, percent sucrose and recoverable white sucrose (RWS) from the second study, 1994, 1995 and 1997.

Nitrogen	Root Yield following		Sucrose following		RWS following	
Rate	F. Bean	Corn	F. Bean	Corn	F. Bean	Corn
kg ha^{-1}	- - Mg ha^{-1} - -		- - g kg^{-1} - -		- - Mg ha^{-1} - -	
0	56.9	38.8	183	180	7.73	5.20
34	63.8	47.5	182	182	8.52	6.39
67	67.9	53.8	184	181	9.21	7.16
101	70.8	62.5	183	184	9.42	8.71
135	72.6	63.2	180	184	9.46	8.59
168	73.9	66.8	178	182	9.49	8.95
202	73.4	70.3	175	182	9.23	9.30
235	74.8	70.9	175	179	9.35	9.25
LSD (5%)	1.8		3		0.32	

field bean and 202 kg following corn. Sucrose concentration declined from 183 to 175 mg kg^{-1} between 67 and 235 kg N ha^{-1} following field bean. However, following corn it was increased from 180 to 184 mg kg^{-1} between zero and 135 kg N and then declined to 179 mg kg^{-1} at 235 kg N. Recoverable sucrose yield was not increased above the 67 kg N rate following field bean, but reached a maximum between 168 and 202 kg N ha^{-1} following corn.

Black (1993) presented a method of soil fertility analysis which utilizes a Baule unit of fertilizer nutrient. The Baule unit is defined as the amount of fertilizer needed to produce 50% relative yield. Following a diminishing increment response, each additional unit produces an additional 50% relative yield (1 unit = 50%, 2 units = 75%, 3 units = 87.5% etc). The maximum yield in the study is set to 100% and from the yield response function generated, fertilizer recommendations for various yield goals may be formulated.

Yield of root and recoverable sucrose was converted to relative yields by setting 74.8 Mg ha^{-1} for root yield and 9.49 Mg ha^{-1} for yield of sucrose to 100% (Table 4). The data following each crop were fit to a quadratic equation using multiple regression, which are presented in Figures 1 and 2. All regression coefficients and the multiple coefficients of determination were significant at the 0.01 level.

The N rate to produce 91, 94 and 97 % yield of roots and recoverable sucrose were calculated from these regression equations and are presented in Table 5. The choice of specific relative yield may be based on commodity price to cost of N ratio, danger to the environment and/or the growers economic situation.

Table 5. Nitrogen rate required to produce yield goals of 91, 94 and 97 % for roots and recoverable sucrose (RWS) based on the quadratic relationships in Figures 1 and 2.

Yield	Root Yield following		RWS following	
Goal	F. Bean	Corn	F. Bean	Corn
%	kg N ha^{-1}			
91	81	176	43	137
94	107	217	62	160
97	144	†	90	200

† Calculated maximum reached below 97% yield (94.9% @ 252 kg N ha^{-1}).

The amount of N needed following corn was between 95 and 110 kg N ha^{-1} greater than following field bean irrespective of yield goal (Table 5). Reasons for this difference could be embodied in soil N supply, soil structure differences or some other factor. Soil analysis data collected in

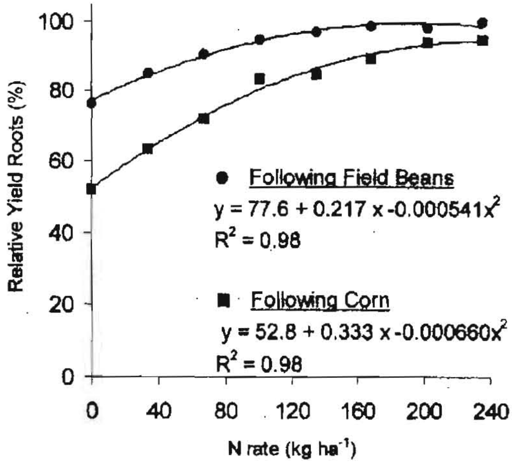

Figure 1. Relationship between relative yield of sugarbeet root and applied N rate following corn and field bean, based on root yield of 74.8 Mg ha^{-1}, Table 3. Each data point is the average of three years data, 1994, 1995 and 1997.

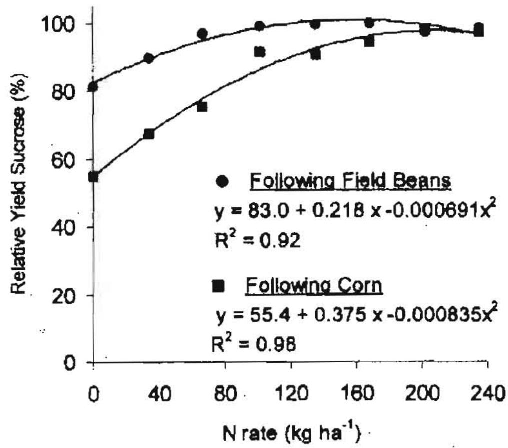

Figure 2. Relationship between relative sucrose yield and applied N rate following corn and field bean, based on recoverable sucrose yield of 9.49 Mg ha^{-1}, Table 3. Each data point is the average of three years data, 1994, 1995 and 1997.

the cropping systems study address the N supply from soil and structural differences.

Lower yield following corn does not appear to be related to soil N as measured by several methods. The reason for selection of various extractants was to extract a fraction or fractions of organic N which may be related to crop uptake. Mineral N (NO_3 + NH_4) values were low and fairly typical of the range found in this soil other years (Table 6). They were

Table 6. Effect of previous crop on soil nitrogen indices from the cropping systems study after 20 years of cropping on a Misteguay silty clay soil, 1992 and 1993.

Soil N Indices	1992 Following		1993 Following	
	F. Bean	Corn	F. Bean	Corn
	- - - - - - - - - mg kg^{-1} - - - - - - - - -			
KCl Extractable NO_3	3.79	4.15	2.38	3.69
KCl Extractable NH_4	7.74	6.06	3.20	2.63
Phosphate-Borate	20.5	23.2†	23.3	26.9†
Anaerobic Mineralization	15.3	22.6†	31.9	34.4
Autoclavable	44.9	48.3	42.2	44.8
Alkaline Permanganate	66.3	70.2†	71.6	72.6
Mineralization Pot.	84.8	94.3†	91.3	109†
Oxidizable C	11900	12400†	10300	10900†

† Means within a year following field bean and corn are significantly different $\alpha = 0.05$.

similar following both crops. The general ranking of the amount of organic N extracted was phosphate-borate=anaerobic mineralization < autoclavable < alkaline permanganate< mineralization potential (Table 6). In every case the amount extracted was significantly greater or tended to be greater following corn than following field bean. Dynamics of N immobilization may play a role in the yield difference observed in this study. These data do not address that issue. However, Yakle and Cruse (1983) suggested the reduced root and shoot weights in the presence of corn residues could not be explained by a reduction in N availability due to immobilization. In the current study, N was broadcast prior to planting at rates well above the recommended amount of 100 to 120 kg ha^{-1}. Consequently, immobilization of N should not have been factor, particularly at the higher N rates.

Another factor affecting growth differences could be soil structure. Measurement of physical properties showed no difference between the two rotations for saturated hydraulic conductivity, total porosity, air porosity, aggregate stability and bulk density (Momen, 1985). However, differences in yield between the two rotations appeared to be related to root growth and leaf area index (Table 7). Net root length and root length den-

Table 7. Effect of previous crop on net root length, root length density, leaf area index and yield of beet root grown on a Misteguay silty clay soil after 11 years of cropping†.

Previous Crop	Net Root Length	Root Length Density	LAI	Root Yield
	‡	cm cm^{-3}	m^2m^{-2}	g m^{-2}
Field Bean	163a§	0.67a	2.32b	6470b
Corn	231b	0.97b	1.68a	5540a

† Momen, (1985).

‡ m plant root (0.0239 m^3 soil)$^{-1}$.

§ Means followed by different letters are significantly different $\alpha = 0.05$.

sity of fibrous roots were greater following corn than following field bean. Conversely, leaf area index (LAI) was greater following field bean than corn. Sugarbeet following corn appears to produce more fibrous roots than following field bean. This seems to be at the expense of leaf size and yield of harvestable roots.

In the study reported here, we did not measure growth of fibrous roots, but leaf area index was measured. The data in Table 8 show a significant effect of previous crop and nitrogen rates on LAI and a fairly consistent trend for lower LAI following corn compared to field bean. The difference seems to increase with time suggesting a latent effect of slower growth early in the season. LAI was increased with increasing N rates at all dates sampled. However, differences were not significant at 70 or 77 days between the 90 and 135 kg N rates. A lack of interaction between N rate and previous crop suggests that the slower growth was not compensated for with increasing N rate. LAI measurements from the second ex-

Table 8. Simple effect of previous crop and nitrogen rate on leaf area index (LAI) of sugarbeet grown in the long term cropping systems study, 1993 and 1994.

Input Parameter	Leaf Area Index: Days After Planting 1993			Days After Planting 1994		
	70	83	112	77	89	103
	m^2m^{-2}					
Previous Crop						
Field Bean	1.77	2.28	2.80	2.46	3.03	3.22
Corn	1.50	1.99	2.22	1.84	2.41	2.56
LSD†	NS	NS	*	+	+	+
Nitrogen Rate (kg/ha)						
0	1.18	1.29	1.56	1.36	1.78	1.95
45	1.67	2.21	2.33	2.15	2.62	2.88
90	1.89	2.44	2.71	2.67	2.99	3.30
135	1.80	2.61	3.26	2.41	3.49	3.88
LSD (5%)	0.35	0.27	0.42	0.34	0.47	0.40

† * significant at $\alpha = 0.05$ and + significant at $\alpha = 0.10$.

periment (not shown) did not indicate a significant interaction between previous crop and nitrogen rate. Even at 180 kg N ha^{-1}, the LAI following corn was less than following field bean.

DISCUSSION

Rotations are an important management tool affecting a number of aspects of sugarbeet production. Forage legumes have been used in numerous rotation studies to supply N, making separation of rotation and N effects difficult. In the current study, forage legumes were not included, but an edible legume was. This legume is an inefficient fixer of N and a range of values between 10 and 125 kg N ha^{-1} has been reported (Piha and Munns, 1987). In the current study, root yield difference for the control following corn and field bean was 15.9 Mg ha^{-1} in Experiment 1 and 18.1 Mg ha^{-1} in Experiment 2. If we use a value of 4.5 kg N Mg^{-1} of sugarbeet

(Christenson et al., 1992), the N content in 15.9 and 18.1 Mg of sugarbeet would be approximately 72 and 81 kg N, respectively. This may be accounted for by the N fixation attributed to field bean by Piha and Munns (1987) although no data were presented for the specific variety (Mayflower) of field bean grown.

Fertilizer N may compensate in corn rotations for N fixed by the field bean crop and the data in Table 5 suggest this may, in part, be the case. The nitrogen rate required for a yield goal of 91 and 94% for either yield of root or recoverable sucrose was nominally 100 kg ha^{-1} greater following corn than following field bean. Calculation of the 97% goal of sugarbeet root was not possible following corn because the regression equation showed a maximum at a yield goal of 94.9%.

Nitrogen recommendations may be based on either root yield or on yield of recoverable sucrose (RWS). These results show that the amount of N needed for sucrose production is approximately 40 to 50 kg ha^{-1} less than for root yield. The course of action by a grower depends on the contract. Growers paid on a per ton basis will fertilize for maximum root yield. Conversely, if payment is based on yield of recoverable sucrose, lower N rates may be used.

Corn residues have been shown to affect subsequent crops including consecutive years of corn. Porter et al. (1997) reported that corn yields were increased by a single year interruption from monoculture corn with either alfalfa (*Medicago sativa* L.) or sunflower (*Helianthus annuus* L.). Long term results from the cropping study, of which these results were a part, showed that a one year break was sufficient to interrupt this yield depression (Christenson, Bricker and Gallagher, 1991). Yield of first year corn following either sugarbeet or field bean was 7.90 Mg ha^{-1} while second and third year corn yielded 6.96 and 6.59 Mg ha^{-1}, respectively.

Allelopathic effects of corn on sugarbeet growth may be one cause for the lower yields. Research has shown that corn residues negatively affect germination, early season growth and yield of subsequent crops. For example, Martin et al. (1990) showed a marked reduction of germination and early growth of corn due to the incorporation of corn residues. Corn has been shown to inhibit the growth of wheat (*Triticum aestivum* L.) (Guenzi et al., 1967) and several other plant species (Lawrence and Kilcher, 1962). However, no studies were found reporting the effect of corn residues on sugarbeet germination and growth.

Another factor contributing to the lower yields following corn could be an interaction between carry-over herbicide used on the corn and that used on sugarbeet. No studies were found which addressed this problem. However, Robertson, Cook and Davis (1976) in a herbicide free experiment reported a 7.5% yield reduction in sugarbeet following corn as compared to field bean. In our study, stand reduction due to carry-over herbicides was not a factor since the beets were planted at 5-cm spacing and hand thinned to 20 cm approximately four weeks after emergence.

While we did not measure moisture content of the soil, little evidence exists to suggest differences in carry-over moisture following corn versus field bean because the soil was saturated in the spring. October - March precipitation prior to planting sugar beet always exceeded the moisture holding capacity of 14 cm to a depth of 90 cm (Table 1). The soil was near field capacity at the beginning of October. Run-off was not a significant factor because the slope of the experimental area was less than 1%. The soil is tile drained and the tile lines flowed in March and April each year indicating the soil was saturated.

We recognize this work does not conclusively evaluate the cause of apparent slower growth following corn. Additional studies are needed to evaluate the effect of corn residues on early growth and development of sugarbeet. These should include evaluation of interactions between herbicides used on corn with those used on sugarbeet, effect of corn residues on early season growth and effect of residues on N availability early in the season.

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