NET RETURNS OF VARLABLE CORN AND SOYBEAN CROPPING SYSTEMS

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FOREWARD

This thesis is written as an manuscript to be submitted to the Journal of Production Agriculture. It is followed by appendixes containing information about soil and plant nutrients not directly referred to in the manuscript.

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TABLE OF CONTENTS

ABSTRACT

Com and soybean grown in sequence is one of the most popular cropping systems in the United States; the com-soybean rotation has enormous importance economically.

The "rotation effect" is known to increase yields of both crops, but little is known about the economic consequences of various corn -soybean rotational patterns compared with monoculture. This study was undertaken to determine the most profitable com-soybean cropping pattern for Minnesota, based on both actual and sensitivlty price analyses. Rotations investigated were: corn monoculture, soybean monoculture, corn grown after two years of soybean, soybean grown after two years of com, and an annual alternation of the two crops. The field study was conducted at three locations: Lamberton, Rosemount and Waseca, MN. Lamberton and Waseca are positioned within the "com belt," whereas Rosemount is positioned beyond the northerly fringe. Actual analysis (1984-1989) indicated that com following two years of soybean was the most profitable cropping system at both com-belt locations. At Rosemount there was no clear net-return pattern. Averaged over all locations, com following two years of soybean was definitely the most profitable cropping system however. Soybean monoculture provided the lowest average retum, and com monoculture had the lowest return:operating cost ratio at all locations. Projection analysis indicated that com after two years of soybean would be the most profitable com-soybean rotation in the Minnesota com belt under all expected com or soybean price combinations. Com monoculture was projected to be the least profitable pattem, and soybean monoculture the second least profitable pattem. Prices did not include govemment supports.

LITERATURE REVIEW - OBJECTIVES

In the United States, the annual rotation (alternation) of corn and soybean is a very c:ommon cropping system (Sundquist et al., 1982). Both com and soybean yield better when grown on land previously sown to the other crop than when grown continuously (Higgs et al., 1976; Slife, 1976; Peterson and Varvel, 1989a and 1989b). In long term studies conducted at Waseca and Lamberton, Crookston et al. (1990) found that compared with monoculture, either com or soybean yielded an average of 8% better when altemated and about 16% better when kept out of monoculture for at least two years.

Early in the 20th Century, Amy (19 17) reported a higher net income per acre from corn grown after legumes than grown continuously. Later, Curtiss (1926) demonstrated that a rotation of four or five years was of more value than a shorter three-year rotation which was defiiitely preferable to a two-year system or to continuous cropping. Recently, the beneficial effect of rotation versus continuous monoculture of com and soybean has been estimated in the U.S. to be worth at least 300 million dollars annually (Sundquist et al., 1982). Crookston (1984) has shown that Minnesota. farmers can raise their net profit on com and soybean by as much as 50% from properly exploiting the rotation effect. Daniel and Mueller (1986) found that com-soybean rotation increased the net profit in the com year and in the soybean year by $36.00 and $20.00 per acre, respectively. In contrast, Voss and Shrader (1979) reported that continuous com was among the most profitable systems, depending on the economic values assigned to the crops. Lazarus et al.(1980) found greater annual returns from continuous com than from a rotational com-soybean system .

Conflicting results about the economics of com-soybean rotation systems justified a closer look at the rotation effect, particularly in terms of net return to the farmer. The first objective of this study was to compare the profitability of five diiferent com-soybean cropping sequences over the six-year period 1984-1989 in Minnesota. The second objective was to predict the most profitable Minnesota corn-soybean cropping pattern for the forseeable future via simulated scenarios based on expected fluctations in commodity prices.

MATERIALS ANDMETHODS

A six-year crop rotation study was established in 1.984 at the Southwest Experiment Station at Lamberton, at the Rosemount Experiment Station, and at the Southern Experiment Station at Waseca, Minnesota. The soils at these locations are : Webster clay loam, Waukegan silt loam, and Nicollet clay loam, respectively. The corn hybrid was 'Pioneer Brand 3780' and the soybean variety was 'Hodgson 78'.

Each experimental area was chisel plowed each fall. Fertilizer N (urea or ammonium nitrate), P (superphosphate), and K (potash) were applied according to University of Minnesota soil test recornrnendations for maximum production of each crop. Herbicides: alachlor (lasso), linuron (lorox), and bentazon (basagran); and insecticides: carbofuran (furadan), terbutos (counter), and chlorpyrifos (lorsban) were applied when necessary for weed and insect control.(appendix 1).

Five different corn and/or soybean cropping sequences (Table 1) were arranged in a randomized complete block design replicated four times. Each plot consisted of eight rows 30 feet long spaced 30 inches apart. There were four replications at each location each year. Grain yield was obtained by harvesting the two center rows from each plot. Yield values were corrected for moisture (reported at 15.5%, and 13.5% moisture for corn and soybean, respectively).

Investigating the economic implications of any agricultural practice requires research on the individual components of a farm, the whole farm, commodity markets, national and international agricultural economies,etc. (Madden and Dobbs, 1988). In accessing incentives to adopt crop rotation sequences, various factors must be accountered. for. Complete enterprise budgets may include all fixed and variable cost and returns associated with the farm. According to Boehlje and Eidman (1984) "The distinction between fixed and variable costs is imporatnt in decision -making. Only variable costs should be considered by the manager in deciding what to produce, how to produce and 'how much to produce in the short run. Fixed costs will remain at the same level regardless of these decisions. Thus, neither fixed cash nor non cash costs should be considered in decision-making".

Our approach was to deal with the operating costs and net returns associated with production activities of a typical Minnesota farrn. We assumed that crop sequence was the only aspect of the farm that varied. Such an economic approach may suffice for decision-making in the area of adopting more valuable crop sequences. Operating costs specifically associated with either corn or soybean, and incurred for the production of that crop were considered. According to our particular situation, adjustmenrs were made by accurately determining the cost of fertilizer, seed, herbicide, and insecticide (table 2). Other operating costs were taken from "What to grow in 1989" (Fuller et al., 1989) (table 3). All operating costs were based on 1989 prices. Revenue per acre was calculated on the basis of the yield of com and / or soybean multiplied by the product price. Operating costs were charged against revenues to obtain per acre net returns. Statistical analysis was via the General Linear Procedure of Statistical Analysis System (SAS, 1985).

A variety of possible net return scenarios were also calculated for a range of com and soybean price combinations. Price combinations were based on com and soybean prices for the 15-year period 1975 to 1989; costs and expenses were maintained at 1989 levels.

RESULTS AND DISCUSSION

Economic analvsis based on 1989 dollar value

The annual grain yield of the five cropping systems are given in table 4. Enterprise budgets for the six year period 1984- 1989 were based on actual yields of corn and soybean grain for each year, and on the 1989 prices for com and soybean of $2.40 and $5.85 per bushel, respectively. Operating costs were also fixed at 1989 values.

Over the six years, retums at Lamberton ranged from $140 per acre per year for continuous soybean to $188 per acre per year for com grown after two successive years of soybean (Table 5). Com following two years of soybean provided a significantly greater retum than any other cropping system. Retums obtained from com monoculture, altemated com and soybean, and soybean grown after two years of com were not significantly different. Soybean monoculture provided the lowest retum.

Waseca results were similar to those obtained at Lamberton. Retums varied from $9 1 per acre per year for soybean grown after two years of com, to $155 per acre per year for com grown after two years of soybean. Com after two years of soybean provided a significantly g-mater retum than any other cropping system. There were no significant differences among the remaining cropping pattems.

At Rosemount, retums ranged from $118 per acre per year for continuous soybean to $147 per acre per year for the altemate com-soybean system (Table 5). Continuous corn and an annual rotation of com and soybean provided nearly equally high retums; continuous soybean provided the lowest retum. Over all locations, retums ranged from $119 per acre per year for continous soybean to $160 per acre per year for com following two years of soybean (Table 5). Com after two years of soybean retumed $33 per acre per year more than the average of all other sequences. Continuous soybean was the least profitable system and retumed $24 per acre per year less than the average of all other sequences. The difference between the most profitable system (SSCSSC) and the least profitable system (SSSSSS) was $46 per acre.

The fact that results from Rosemount were so different from the other two locations is worthy of some discussion. Rosemount is located north of the other two sites, and has a strikingly different soil type (appendix 2). Soils at the three locations are classified as follows: Lamberton, Webster clay loam (fine, loamy, mixed, mesic Typic Haplaquoll), Waseca, Nicollet clay loam (fine, loamy, mixed, mesic Aquic Hapludoll) ; Rosemount, Waukegan silt loam (fine, silty over sandy, skeletal, mixed, mesic Typic Hapludolls)). Soil depth at both Lamberton and Waseca is greater than 6 feet, whereas soil depth at Rosemount is about 20 inches below. Lamberton and Waseca are located well within the "com-belt" region of Minnesota, whereas Rosemount lies beyond the northem fringe. The Lamberton and Waseca results thus represent. typical com-belt soil and climatic conditions, whereas the Rosemount results better represent more marginal conditions.

Corn after two successive years of soybean was the most profitable cropping sequence at both Lamberton and Waseca. Hesterman et al. (1987) demonstmted higher gross margins for com and soybean in rotation than for continuous com at these same locations. Results obtained by some authors have shown that gross returns were significantly influenced by rotation in comparison with monoculture (Zetner and Campbell. 1988; Jansen et al.,1987). Our results contradict those of Lazarus et al. (1980) who concluded that monoculture of com was more profitable than rotation.

To estimate the relative efficiency of each cropping sequence, we calculated return/operating- cost ratios (Table 6). A low value for this ratio represents a situaton which could contribute to cash flow problems for some farmers. At Rosemount, for example, retums from continuous com, alternate com-soybean, and com after two years of soybean were quite low. Continuous com had the lowest return/operating cost ratio for all locations (Table 6). If credit is limited, farmers would certaintly consider crops with highest net retum-operating cost ratios, which give enough net return to cover operating costs incurred.

Sensitivity analvsis based uDon combinations of com and sovbean prices

The average retums in Table 5 were based on actual yields, prices and costs during the period 1984-1989. While these retums may be of interest from a historical standpoint, they are of limited value in projecting future retums even from these same cropping sequences in these same locations. In order to obtain some estimate of expected retums from com and soybean grown in various sequence combinations on these sites in the future, we developed several expected-retum scenarios based on projected yields and prices at these sites. Yields for the scenarios were the yields from this six-year (1984-1989) study. Costs were 1989 costs. Prices were derived from average com and soybean prices in Minnesota over the 15-year period 1975- 1989 (Table 7).

From Table 7, we chose the lowest (1986) price of $1.46 per bushel, the highest (1983) price of $3.05 per bushel, and a somewhat medium (1989) price of $2.40 per bushel for com. We then used the 15-year average soybean:corn ratio of 2.7 for a medium ratio. High (3.2) and low (2.2) ratios were determined by adding and subtracting the 15-year ratio standard deviation. This provided nine com-soybean price combinations which we considered to reflect prices likely to be encountered in the future.

With a low com price, com following two years of soybean provided the consistently highest projected retums at both Lamberton and Waseca regardless of the soybean:com price ratio (table 8). Continuous soybean also provided a high. retum when the soybean:com price ratio was 3.2. At Rosemount there was no clear net retum pattem, except that continuous com provided the lowest retum under all soybean:com price ratios.

With a medium com price, com following two years of soybean again provided the consistently highest projected retum at both Lamberton and Waseca. At Rosemount, there was once again no clear trend (table 8).

With a high com price, highest retums again carne from the SSCSSC cropping sequence at both of the com-belt (Lamberton and Waseca) sites, regardless of the soybean:corn price ratio (table 8). At Rosemount, there was no clear pattern.

In order to better visualize the projected performance of the five sequences, the results of each com price and soybean:corn price ratio combination were portrayed by rank (Table 9). The superiority of the SSC pattem at the Lamberton and Waseca locations is clear. It can also be seen that continuous com achieved the number 5 ranking more than any other sequence at these two locations. With only two exceptions, whenever continuous com was not ranked 5th, continuous soybean filled the number 5 rank. In the two exceptional situations, the 5th ranked sequence was CCS. Thus it is clear that monoculture of either crop, but especially of com, is likely to result in lowest returns for farmers in the Minnesota com belt unless future prices fluctuate considerably from the 1975- 1989 pattem.

At Rosemount, there was no clear ranking trend. CSCSCS was projected to be more profitable four times, SSSSSS three times, and CCCCCC two times. The CCSCCS and SSCSSC sequences were never projected to be most profitable.

CONCLUSION

This study was conducted under the condition of crop selection being limited to com and soybean, with resulting cropping systems being some sequential combinations of these two crops. We conclude that choice of com soybean cropping sequence can be of considerable economic importance for Minnesota farmers. The sequence of soybean-soybean-com (S S C) clearly was (and is projected to be) the most profitable sequence across all locations, but especially at the two com-belt locations. However, not all farmers in the state can adopt such a system, other factors, particularly government prices will influence crop selection.

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Table 1. Cropping sequences maintained at Lamberton, Rosemount, and Waseca during the six year period 1984 to 1989. (C=corn; S=soybean).

Treatment	1984	1985	1986	1987	1988	1989
	-------------		crop		-------------	
1	c	c	c	c	c	c
2	s	s	S	S	S	S
3	c	s	c	s	c	s
4	c	c	s	c	c	s
5	S	S	c	s	S	C

Table 2. 1989 prices of inputs used in the analysis

Seed		
corn	21.00	\$ $acre^{-1}$
soybean	9.00	"
Fertilizer		
N	0.12	\$ $pound^{-1}$
P	0.22	"
K	0.14	"
Herbicide		
Lasso	4.80	"
Lorox	12.10	"
Basagran	13.20	"
Crop. oil	5 7	\$ $pint^{-1}$
Insecticide		
Furudan	8.70	\$ $ounce^{-1}$
Counter	8.70	"
Lorsban	8.70	"

Table 3. Estimated operating costs for corn and soybean grown at three locations in Minnesota. From Fuller et al., 1989.

	Lamberton		Rosemount		Waseca	
	Com	Soybean	Com	Soybean	Com	Soybean
	--------------- $ acre^{-1} ---------------					
Fuel	7.59	5.04	7.59	5.07	7.59	5.06
Repairs & Maintenace	19.79	14.98	19.79	15.00	19.59	14.97
Other cash expenses[†]	28.75	-	37.50	-	38.75	-
Interest on cash exp.	7.56	4.66	8.71	4.60	8.67	4.38
Crop Insurance	6.04	6.65	8.06	7.18	8.14	7.18
Total	**69.73**	31.33	81.65	31.89	82.94	31.59

† harvest, drying, purchased irrigation, custom operations, technical services.

Table 4. Average grain yield of cropping sequences maintained at Lamberton, Rosemount. and Waseca during the six year period 1984 to1989. (C=corn, S=soybean).

Lamberton

Treatment	1984	1985	1986	1987	1988	1989
	-------- grain	yield(bu.	acre^{-1})	--------		
1. C C C C C C	133	160	136	140	54	137
		38		44	35	38
3. C S C S C S	[illegible]	42	[illegible]	48	71	37
4. C C S C C S	127	170	35	149	70	39
5. S S C S S C	40	40	183	51	31	146

Rosemount

Treatment	1984	1985	1986	1987	1988	1989
	-------- grain	yield(bu.	acre^{-1})	--------		
1. C C C C C C	147	89	169	163	22	125
2. s s s s s s	39	27	42	42		
3. C S C S C S	156	29	181	44	118	34
4. C C S C C S	127	96	40	169	70	40
5. S S C S S C	34	26	184	45	24	11

Waseca

Treatment	1984	1985	1986	1987	1988	1989
	-------- grain	yield(bu.	acre-')	--------		
1. C C C C C C	95	133	137	145	85	144
2. S S S S S S	30	25	39	41	27	39
3. C S C S C S	81	30	132	48	63	40
4. C C S C C S	89	122	44	129	25	37
5. S S C S S C	32	27	133	46		194

All locations combined

Treatment	1984	1985	1986	1987	1988	1989
	-------- grain	yield(bu.	acre^{-1})	--------		
1. C C C C C C	125	127	147	149		135
				42	74	36
3. C S C S C S	[illegible]	[illegible]	[illegible]	47	68	37
4. C C S C C S	114	129	40	149	27	38
5. S S C S S C	35	31	167	47		153

Table 5. Average returns based on history of cropping systems (1984-1989)

Treatments	Lamberton	Wascea	Rosemount	locations combined
	location			
	-------- return ($ acre-1 year-1) ---------			
CCCCCC	156 b	108 b	145 a	136 b
ssssss	140c	99 b	118 c	114 d
cscscs	159 b	95 b	147 a	134 bc
ccsccs	156 b	91 b	123 bc	123 c
sscssc	188 a	155 a	138 ab	160 a
C.V. (%)	6.5	18.0	8.4	10.4

* Within each column means with the same letter are not significantly different at the 0.05 probability level according to Duncan's Multiple Range Test.

Table 6. Return:operating cost ratios of the five cropping systems.

Treatments	Lamberton	Rosemount	Waseca
	------	- ratio* ----------	
1 - cccccc	----	0.57	0.88
2 - ssssss	1.87 1.06	1.03	1.50
3 - cscscs	1.37	0.63	1.20
4 - ccsccs	1.28	0.61	0.89
5 - sscssc	1.82	1.29	1.29

$$* \text{ ratio} = \frac{\text{return (\$/acre/year)}}{\text{operating cost (\$/acre/year)}}$$

Table 7. Average annual prices paid to Minnesota fax-mers.

Year	Price of Corn	Price of Soybean	Soybean:Corn price ratio
	--- $ bushel -[1] ---		
1975	2.50	5.02	2.01
1976	2.03	7.22	3.55
1977	1.90	5.90	3.11
1978	2.08	6.52	3.13
1979	2.26	6.00	2.65
1980	2.85	7.23	2.54
1981	2.33	5.77	2.48
1982	2.63	5.81	2.21
1983	3.05	7.64	2.50
1984	2.47	5.60	2.27
1985	2.05	4.98	2.43
1986	1.46	4.72	3.29
1987	1.55	5.70	3.68
1988	2.35	5.50	2.34
1989	2.40	5.80	2.42
		Mean	2.70
		Std. Dev.	0.50
		Low	2.01
		High	3.68

Source: Minnesota agricultural statistics
(prices do not include government support).

Table 8. Sensitivity analysis: returns above operating costs ($/acre/year) for selected com prices and soybean:corn (S:C) ratios at Lamberton, Rosemount, and Waseca.

Com price = $1.46/bu (low)

Treatments	Lamberton S:C ratio 2.2	2.7	3.2	Rosemount S:C ratio 2.2	2.7	3.2	Waseca S:C ratio 2.2	2.7	3.2
	$ acre^{-1} year^{-1}								
1. cccccc	37 b*	37d	37d	24bc	24b	24 d	•8 c	•8 c	•8 c
2. SSSSSS	41 b	69 b	97a	30 ab	55 a	75 a	12 b	36 b	61 a
3. CSCSCS	45 b	5oc	76 c	36 a	49a	62b	-4 bc	10 c	25 b
4. CCSCCS	43 b	6Obc	61 c	16 c	26b	36 c	•8 c	3 c	13bc
5. sscssc	65 a	85 a	105 a	36 a	51 a	67 b	39 a	58 a	78 a
C.V. (%)	14	11	9	24	18	14	100	70	55

Corn price = $2.40/bu (medium)

Treatments	Lamberton S:C ratio 2.2	2.7	3.2	Rosemount S:C ratio 2.2	2.7	3.2	Waseca S:C ratio 2.2	2.7	3.2
	$ acre^{-1} year^{-1}								
1. cccccc	156 b*	156b	156d	145a	145ab	145b	1108 a	108 b	108 c
2. ssssss	121 c	167b	213b	101 c	141 ab	189a	81 b	1120 b	'162 b
3. cscscs	148b	173'b	198b	138 a	160a	181 a	84 b	108 b	131 bc
4. ccsccs	149 b	164 b	179 c	116bc	132b	148b	84 b	100 b	117 c
5. sscssc	173a	203 a	238a	127ab	152a	178 a	1.41 a	173 a	206 a
C.V. (%)	7	6	6	9	8	7	18	18	19

Com price = $3.05/bu (high)

Treatments	Lamberton S:C ratio 2.2	2.7	3.2	Rosemount S:C ratio 2.2	2.7	3.2	Waseca S:C ratio 2.2	2.7	3.2
	$ acre^{-1} year^{-1}								
1. cccccc	239 ab*	239 b	239 c	229 a	229 ab	229 b	1188 a	1188 b	188 b
2. SSSSSS	176 c	239'b	294 b	149d	201 c	253 a	129 b	180 b	231 b
3. CSCSCS	219b	251 b	284b	209 ab	236a	264a	1147 b	1175 b	205 b
4. CCSCCS	223 b	241 b	260 c	185 c	206 b	226 b	1145 b	168 b	'189 b
5. sscssc	247a	289 a	330a	191 bc	223 abc	256 a	211 a	253 a	294 a
C.V. (%)	6	6	5	7	7	6	14	14	15

* within each column means with the same letter are not significantly different at the 0.05 probability level according to Duncan's multiple range test.

Table 9. Ranking of returns for five cropping systems at Lamberton, Waseca, and Rosemount for different combinations of com prices, and corn:soybean price ratios.

Lamberton

	Com Price								
	I$dv46/bu)			Med($2.40/bu)			High ($3.05/bu)		
	Soybean:corn ratio			Sovbean:corn ratio			Soybean:corn ratio		
Treatment	2.2	2.7	3.2	2.2	2.7	3.2	2'2	2.7	3.2
	ranking*								
1 cccccc	5	5	5	2		5	2	5	5
2 ssssss	4	3	2	5	3	2	5	4	2
3 - cscscs	2		3	4	2	3	4	2	3
4 - ccsccs	3	4	4	3	4	4	3	3	4
5 - sscssc	1	1	1	1	1	1	1	1	1.

Rosemount

	Com Price								
	Low ($1.46/bu)			Med($2.40/bu)			High ($3.05/bu)		
	Soybean:corn ratio			Soybean:corn ratio			Soybean:corn ratio		
Treatment	2.2	2.7	3.2	2.2	2.7	3.2	2.2	2.7	3.2
				ranking*					
								2	2
2 - ssssss	3	3	3	4	4	5	5	5	4
1 - cccccc	1	5	5	3/5	1		2	1	1
4 - ccsccs	5	4	4	3	5	4	4	4	5
5 - sscssc	2	2	2		2	3	3	3	3

Waseca

	Com Price								
	Low ($1.46/bu)			Med($2.40/bu)			High ($3.05/bu)		
	Soybean:corn ratio			Sovbean:com ratio			Sovbeanxom ratio		
Treatment	2.2	2.7	3.2	2.2	2.7	3.2	2.2	2.7	3.2
	ranking*								
1 cccccc	5	5	5	5	4	5	2	2	5
2 - sssssss	2	2	2	3	2	2	5	3	2
3 - cscscs	3	3	3		3	3	4	4	3
4 - ccsccs	4	4	4	4	5	4	3	5	4
5 - sscssc	1	1	1	1	1	1	1	1	1

* ranking of 1 = the most profitable sequence; 5 = the least profitable sequence.

Appendix 1: Rates of inputs applied on plots at Lamberton, Rosemoun t, and Waseca from. 1984 to 1989

	Fertilizer (# per acre)			Herbicides (#peracre)				Insecticides (oz.per 100 ft)		
	N*	P	K	lasso	lorox	basagran	oil	furadan	counter	losban
LAMBERTON										
1984	125	100	100	2.5	2.5	-	-			
1985	125	100	100	2.5	1.5	-	-			
1986	125	-	-	2.5	1.5	-	-			
1987	125	-	-	3.0	1.5	-	-		1.0	
1988	125	100	100	2.5	1.5	-	-	1.0		1.0
1989	130	-	-	3.0	1.5	-				1.0
ROSEMOUNT										
1984	-	-	-	-	-	-	-			
1985	160	-	-	2.5	-	1.0	-		1.0	
1986	160	-	-	2.5	-	1.0	-		1.0	
1987	180	-	-	2.5	-	1.0	2.0		1.0	
1988	170	-	-	-	-	-	2.0		1.0	
1989	160	-	-	2.5	-	1.0	2.0			1.0
WASECA										
1984	163	-	-	3.5	1.5	-	2.0	1.0		
1985	175	-	-	-	-	-	2.0	1.0		
1986	175	-	-	3.0	1.5	-	2.0	1.0		
1987	175	-	-	3.5	1.5	1.0	2.0		1.0	
1988	163	-	-	3.5	1.5	-	2.0		1.0	1.0
1989	163	-	-	3,5	1.5	1.0	2.0			1.0

* Nitrogen was applied only on plots planted to com.

Appendix 2: Soil characteristics

Lamberton: Webster: fiie loamy. mixed,Typic Hapluquoll

-slope 0-3%

-poorly drained soil on glacial moraines

-surface layer black granular or blocky, friable clay loam or loam 14 to 16 inches thick

-subsurface layer very dark gray to olive gray, friable clay loam 19 to 21 inches thick, certain few mottles

-underlaying material strongly mottled, gray calcareous loam, substrats with many lime concretions, 32to37 inches thick

-available water capacity: 15.6 inches to 5 feet

-high organic mater: 6-7%

-moderately permeable

Waseca: Nicollet: fine loamv. mixed.Aauic Hanludoll

-slope: 0-2%

-moderately well draïned soil on the uplands

-surface layer black to very dark grayish brown clay loam 8 to 16 inches thick

-subsurface dark grayish brown clay loam 2 5 to 35 inches thick

-underlaying material olive gray calcareous loam or clay loam

-avalaible water capacity: 9.5 inches to 5 feet

-high organic mater: 6%

-moderately permeable

Rosemount: Waukegan: fine silt loam. mesic,Typic Hapludoll

-slope: 2-6%

-well drained soil

-surface layer black silt loam about 14 inches thick

-subsurface layer dark grayish brown silt loamabout 3 inches thick

-underlaying material dark brown sand about 4 inches thick

-avalaible capacity: 10.7 inches to 40 inches

-organic mater: 2-6%

-moderately permeable in uuper mantles and rapid in underlaying soil and bedrock

Appendix 3.1 Soil levels of extractable phosphorus and exchangeable potassium as affected by crop history.

	LAMBERTON				
Crop to be plauted	C	S	S	C	S
No.of years of C out of previous 5	5	3	2	1	0
No.of yeasr of S out of previous 5	0	2	3	4	5
Soil P(lb.acre-1)	50	51	54	57	57
Soil K (lb.acre- 1)	263	277	330	310	330

	ROSEMOUNT				
Crop to be plauted	C	S	S	C	S
No.of years of C out of previous 5	5	3	2	1	0
No.of years of S out of previous 5	0	2	3	4	5
Soil P(lb.acre-1)	68	60	81	70	83
Soil K(lb.acre- 1)	257	268	276	279	316

	WASECA				
Crop to be plauted	C	S	S	C	S
No.of years of C out of previous 5	5	3	2	1	0
No.of years of S out of previous 5	0	2	3	4	5
Soil P(lb.acre-1)	69	88	76	79	88
Soil K(lb.acre-1)	388	397	406	409	411

	ALL LOCATIONS COMBINED				
Crop to be plauted	C	S	S	C	S
No.of years of C out of previous 5	5	4	3	1	0
No.of years of S out of previous 5	0	2	3	4	5
Soil P(lb.acre-1)	62	66	70	69	76
Soil K(lb.acre- 1)	303	314	337	322	352

Important points

1. Com monoculture reduced soil P and K levels as compared to soybean monoculture.
2. There was a trend of increasing soil P and K with decreasing frequency of years of com during the last 5 years.

Appendix 3.2: Com (C) and soybean (S) leaf concentration of P and K at flowering (com=silking, soybean=R3) in 1989.

	Lamberton		Rosemount		Waseca	
	P	K	P	K	P	K
	......................g.kg-1...........................					
Continuous C	3.0	17.8	3.5	12.9	2.9	17.0
C after 2 years of S	2.9	18.0	3.5	12.9	2.8	17.0
Continuous S	4.5	18.9	6.5	21.8	6.0	21.9
S after 1 year of C	4.6	19.9	6.7	21.8	5.7	21.9
S after 2 years of C	4.5	18.5	7.0	23.0	6.1.	22.7

Important point

Com and soybean leaf concentration of P and K was not affected by the rotation history.

Appendix 3.3: Leaf concentration of Ca, Mg, Fe, Mn, Zn, Cu, and B in com (silking stage) and soybean (R3 stage) plants in 1989.

	Ca	Mg	Fe	Mn	Zn	CU	B
	. ..g.g-1...		........".......		mg.g-1...............		
LAMBERTON							
Continuous C	5.6	4.7	124.5	55.0	21.5	9.5	6.3
C after 2 years of S	5.2	4.5	133.0	55.0	24.0	10.3	6.6
Continuous S	8.4	4.4	92.3	41.5	32.5	7.0	37.0
S after 1 year of C	8.3	4.2	90.5	44.5	32.5	7.0	36.0
S after 2 years of C	8.5	4.4	93.0	41.5	32.0	7.0	37.5
ROSEMOUNT							
Continuous C	6.7	8.1	154.0	54.0	22.0	11.0	6.0
C after 2 years of S	6.8	8.3	162.0	57.0	23.0	10.5	5.5
Continuous S	10.2	5.3	98.3	59.0	42.0	5.6	40.0
S after 1 year of C	9.2	5.1	95.8	57.0	43.3	7.5	39.0
S after 2 years of C	9.3	5.1	95.0	54.0	45.5	10.0	38.5
WASECA							
Continuous C	4.9	4.1	150.0	27.0	25.0	8.0	5.0
C after 2 years of S	5.0	4.4	128.5	25.5	22.5	8.8	5.5
Continuous S	10.3	4.9	101.0	44.0	41.5	8.0	47.5
S after 1 year of C	10.3	4.7	101.5	47.0	42.5	9.3	46.5
S after 2 years of C	10.0	4.5	96.5	46.3	41.5	9.5	47.5

Important points

1. Com and soybean concentration of Ca, Mg, Fe, Mn, Zn, Cu., and B was not affected by the rotation history.
2. Ca and B concentration was greater in soybean leaves than in com leaves.
3. Fe concentration was higher in com leaves than in soybean leaves.