Phosphorus and Potassium Experiments on Well-Managed Soils IN SOUTH-CENTRAL MINNESOTA

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ON THE COVER: This bountiful field of corn will yield nearly 200 bushels per acre. This publication reports research in Martin and Waseca Counties to determine how high fertilizer levels must be before broadcasting can be discontinued.

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Introduction

High-producing cornfields in Minnesota are generally on soils built up to a high degree of fertility. This buildup is primarily from liberal broadcast applications of phosphorus (P) and potassium (K) fertilizers.

Historical review

Before 1950, only small amounts of commercial fertilizer were used for corn, usually in row applications. As farmers strived for higher yields, they increased these rates. The oldstyle "split boot" applicator allowed some fertilizer to come into contact with the seed. With the higher application rates, germination damage resulted. The next improvement was "2 x 2" placement. Row fertilizer was placed 2 inches to the side and 2 inches below the seed to protect the kernels. High rates could then be applied in the row without damage, but keeping the fertilizer boxes filled slowed the planting operation.

Bulk spreading came into use in the 1950's. First, modest quantities were applied using this method. Later, as fertilizer prices declined, higher and higher rates were used. The amount in the row could be greatly reduced. Farmers once again began placing the fertilizer on or near the seed. "Pop-up" fertilizer came into being. Broadcast fertilizer had reduced and, in some cases, eliminated the need for row fertilizer.

Fertility buildup, together with improved hybrids plus greatly improved weed and insect control, brought about outstanding corn production. Yields of 150 to 175 bushels per acre were not news anymore.

Fertilizer prices took a significant drop in the late 1960's, and they continued low in the early 1970's. This tremendous price benefit and high yields brought on even higher rates of broadcast fertilizer. As a result, soils in many corn-growing areas were very high both in phosphorus and potassium.

A substantial increase in fertilizer prices occurred in 1974 and 1975. Nitrogen quadrupled over its price 2 years earlier. Phosphorus prices doubled to tripled over their earlier values. Potash costs have doubled and may go higher. The need for efficient use and careful dollar expenditure on fertilizer suddenly returned.

Need for present research

Liberal fertilizer applications have brought up the question, "How high must fertility levels be before broadcasting can be discontinued?" In 1969, experiments were begun in Martin and Waseca Counties to answer these and other questions.

Objectives

1. To evaluate the University of Minnesota computerized fertilizer recommendations so maximum and efficient crop production can be achieved through optimum fertilizer use.
2. To observe the long term effects on yield of continuous corn from broadcast and row P and K applications on soils already testing very high in these elements.

*Overdahl and Fenster are extension soils specialists. Randall is a soil scientist at the Southern Experiment Station in Waseca.

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We are grateful to Roy Lukken, owner of the Waseca County plots. The plot area was rented from Mr. Lukken, and field operations were conducted by personnel from the University of Minnesota Experiment Station-Waseca. Thanks to Vern Ferch, plot supervisor, and to the workers from the station who harvested the corn each year. The original establishment of these plots was done by R. D. Frazier, former soil scientist at the Waseca Station, and his fine efforts are acknowledged as well as the cooperative effort of Dick Anderson, Experiment Station superintendent. Gyles Randall later assumed the position held formerly by Russell Frazier.

Thanks also go to the plot supervisors from the University of Minnesota-St. Paul. They are former Research Assistant Dean Fairchild and research assistant Robert Schoper. Others helping during the 6 years of these trials were Bob McCaslin, Paul Groneberg, Jerome Lensing, and Charles Behrens, assistants in the University of Minnesota Agricultural Extension Service, and Abelardo Castro, Extension Specialist in Soils.

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Materials and methods

Soils

Waseca County soils[1]

Soils of the K experimental area on the Lukken farm are principally LeSueur clay loam (aquic argiudolls),[2] with some Cordova silty clay loam (Typic Argiaquolls).

The LeSueur series consists of dark-colored, deep soils that are moderately well-drained to somewhat poorly drained. They developed under hardwood forests. The surface layer is black to very dark gray, slightly acid to medium acid clay loam 8 to 12 inches thick. The subsoil is very dark grayish-brown, medium acid to strongly acid clay loam 30 to 40 inches thick. The underlying material is light olive-brown calcareous loam or clay loam.

These nearly level (0-2 percent slope) LeSueur clay loam soils are moderately permeable. Their natural fertility and moisture-supplying capacity are high. They have few limitations for farming and are used intensively for row crops.

The P experimental site had principally Cordova silty clay loam soils with small LeSueur clay loam areas.

The Cordova series consists of black, deep, poorly drained upland soils. These soils are nearly level and are on the tops of somewhat circular hills or on broad flats and in small, shallow depressions. These soils also developed under hardwoods.

The surface layer is black, neutral to slightly acid silty clay loam 6 to 10 inches thick. The subsoil is dark gray or very dark gray, medium acid to slightly acid silty clay loam, light silty clay, or clay loam 15 to 30 inches thick. The underlying material is olive, firm, calcareous clay loam.

The Cordova silty clay loam, 0 to 2 percent slope, requires drainage. If adequately drained, this soil is highly productive. Row crops can be grown intensively.

On the Lukken farm, adequate tile drainage has been installed through the entire experimental area.

Martin County soils

The P experiment was located on the Canisteo series (Typic Haplaquolls). This series[3] consists of deep, poorly drained, limy soils on flats and slightly elevated rims around depressions. These fine-textured soils developed in calcareous glacial till where the original vegetation was tall grass prairie. The surface layer is black and very dark gray, silty clay loam about 20 inches thick. The subsoil, about 11 inches thick, is a dark gray to gray, mottled clay loam. The underlying material is olive gray mottled clay loam glacial till. Canisteo soils have high water storage capacity and high organic matter content and moderate natural fertility. Permeability is moderate, and drainage is needed for maximum productivity. Associated series are Glencoe, Webster, Harps, and Nicollet soils.

The K experiment was on a soil similar to that of the P plot site; however, since the surface pH is less than 7, it is classified as a Webster. The Webster[4] silty clay loam (Typic Haplaquolls) is described as a deep, dark-colored, imperfectly to poorly drained soil. This soil has developed from friable medium-textured limy glacial till parent material. The topsoil is about 14 inches thick and has a slightly acid to neutral reaction. From 14 to 21 inches, it is a dark gray silty clay loam with a slightly acid to neutral pH. From this depth to 30 inches, it is an olive-colored calcareous silty clay loam; beyond 30 inches, it is highly calcareous.

The Dahl farm has adequate tile drainage installed through the experimental area.

Weather

Appendix tables 1a and 1b show precipitation records from near the plots. The Fairmont weather station is approximately 12 miles northwest from the Martin County plot area. The Waseca Experiment Station weather station is 5 miles east of the Waseca County plot area.

Rainfall in Martin County was adequate in 1972, but hail reduced yields. High rainfall in early season some years prevented adequate warming of soils; row fertilizer in these years was usually most beneficial.

Severe hail damage was incurred on the Waseca County plots in 1974. Also in that year, frost damaged the corn at both sites Sept 3.

Experimental area

The Martin County site was located on the Fred Dahl farm 5 miles south and 10 miles east of Fairmont. The Waseca County site was on the Roy Lukken farm 5 miles west of Waseca.

Experimental design and fertilizer treatments

Phosphorus trial

Identical experimental designs were used at the two sites in Martin and Waseca Counties. Broadcast P treatments were 0, 50, 100, 150, and 200 pounds per acre of phosphate (P_2O_5). A randomized complete block design was used with eight replications. All treatments were split, half receiving row fertilizer and half with no row treatment (figure 1, appendix). The annual row fertilizers applied in Martin and Waseca counties were 10 + 40 + 40 and 13 + 34 + 45 pounds per acre of N, P_2O_5 and K_2O, respectively.

Broadcast applications of 200 pounds of N and 200 pounds of K_2O per acre were made annually across all plots. In each of the first 2 years of the trial in Martin County, 20 pounds per acre of zinc (Zn) as zinc sulfate were applied to insure adequate Zn. The same Zn rate was applied at Waseca in 1972.

Each individual plot in Martin County was 40 feet long and 15 feet wide (6 30-inch rows); in Waseca County, the plots were 100 feet long and 10 feet wide (4 30-inch rows).

Potassium trial

The K experiment was conducted in much the same way as was the P trial.

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[1]Soil Survey, Waseca County Series 1961, No. 24, 1965.

[2]Tentative classification of soil series of Minnesota in the comprehensive system, USDA, SCS.

[3]Soil Conservation Service, USDA.

[4]Soil Survey Series 1947, Soil Conservation Service, USDA, "Faribault County Minnesota Soils."

Treatments and design were the same for both sites. The treatments were 0, 50, 100, 200, and 400 pounds per acre of K_2O. These were randomized within each of the eight replications. As with the P trial, all plots were split; half of each broadcast plot received row fertilizer rates identical to those in the P trial.

Applications of 200 + 150 + 0 were broadcast annually, and zinc was applied over all plots as described above. Plot sizes were identical to those in the P experiment.

Seed, pesticide, and tillage

Martin County

Minhybrid 4201 was used during each of the 5 years of the trial. The final population was approximately 25,000 plants per acre each year. This is a 110-day relative maturity hybrid. Furadan was used to control root worm, and Lasso was used as the herbicide. Control of insects and weeds was very effective.

Land was fall-plowed after P and K fertilizer was broadcast. In the spring, land was tilled with a tandem disc pulling a harrow before planting, and nitrogen was spring-applied. Corn was cultivated twice.

Waseca County

Minhybrid 4201 was used in 1970 and planted at 28,000 plants per acre. Northrup King PX47E was planted at approximately 26,000 from 1971 to 1974. Planting dates varied, but corn was planted as early as weather permitted. Generally, this was the last week of April or the 1st week of May.

Furadan was applied at planting time to control corn rootworms, and a mixture of Lasso and Atrazine was applied to control weeds. Very effective insect and weed control was obtained.

Land was fall-plowed after P and K fertilizer treatments were made. Nitrogen was applied in the spring. Plots were double-disked and harrowed before planting. Corn was cultivated twice during June or rotary-hoed in May and cultivated once. These practices varied from year to year.

Harvesting

Corn was hand-harvested except for 1 year in Waseca County. Two 20-foot rows were harvested from each plot; care was taken to select uniform stand. Corn was weighed as ear corn. Ten ear samples were selected randomly from each plot, and moisture was determined from them. Yields were calculated at 15½ percent moisture.

Plant and soil analyses

Soil samples to a 6-inch depth were taken between the rows each October. All samples were air-dried and routinely analyzed at the University of Minnesota Soil Testing Laboratory.

Exchangeable K was extracted[5] with normal neutral ammonium acetate, using a soil-solution ratio of 1 to 5. Samples were shaken for 1 minute before filtering, and K in the filtered extract was read on a flame emission spectrophotometer.

Extractable soil P[5] was extracted with 0.03 *N* ammonium fluoride in 0.025 *N* hydrochloric acid (Bray-1 extractant). One gram of soil and 10 milliliters of extractant were shaken for 1 minute, and 5 ml of filtered solution were treated with ammonium molybdate and amino-naphthol-sulfonic acid solution. The intensity of a resulting blue color was read on an absorption spectrophotometer.

Soil pH[5] was determined using a glass electrode pH meter on a 1 to 1 soil-water suspension.

The first leaf opposite and below the ear was sampled each year during silk emergence. Ten leaves per plot were taken. Leaves were oven-dried and analyzed in a multi-element emission spectrophotometer at the University of Minnesota for P, K, Ca, Mg, Fe, Zn, B, Mn, and Cu. Nitrogen was determined by Kjeldahl method.

Results and discussion

Initial soil analyses

Martin County

Five soil samples were taken in fall 1969 from each of the two plot areas. These represent the initial fertility levels of the P and K experimental sites. The average results are:

Experiment	pH	P	K	Texture
P	7.7	46	300	SiCL
K	6.4	44	280	SiCL

Plots were located beginning 70 feet from a field boundary along a gravel road. The P plot, therefore, extended from 70 to 270 feet in from the edge of the field.

Only two plots of 40 had a pH below 7 and two between 7 and 7.4. All other pH values in the P plot area ranged from 7.5 and 8.1.

In the K plot area, only 3 out of 40 plots had a pH above 7. The K experiment extended 270 to 470 feet from the field road boundary. The break in pH differences occured between the P and K plot boundaries.

Waseca County

Averages from four samples for each of the respective plot areas in 1970 are:

Experiment	pH	P	K	Texture
P	6.4	34	310	SiCL
K	6.2	53	260	SiCL

Potassium broadcast on the P site and P broadcast on the K site are reflected in these tests. P and K levels from the respective experiments are from check plots not treated with these nutrients; these represent valid initial P and K readings for each experiment.

Broadcast phosphorus effect

The high initial P soil test levels and those on the check plots throughout the experiment appear to be adequate to sustain highest possible corn yields during each of the 5 years of the trials. Tables 1 and 2 show yields

[5]Grava, J. Soil analysis methods as used in University of Minnesota Soil Testing Laboratory, Institute of Agriculture, Forestry, and Home Economics University of Minnesota, April 1968.

Table 1. 1970 through 1974 corn yields, plant analyses, and soil tests in *Martin County* according to broadcast *phosphorus* treatment

P_2O_5	Yields bu/acre					Percent P leaves					Soil test P lbs/acre				
lbs/A	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974
0	155	137	136	160	151	.26	.28	.37	.27	.30	46	37	47	35	57
50	151	137	127	157	146	.26	.27	.39	.27	.33	36	39	47	50	78
100	162	156	136	160	153	.27	.30	.40	.29	.34	56	55	96	81	101
150	146	146	129	153	150	.28	.30	.39	.29	.35	65	63	94	85	102
200	145	154	130	158	149	.28	.28	.38	.30	.37	64	55	109	88	100
	ns	+	ns	ns	ns	ns	ns	ns	*	*					

	1970	1971	1972	1973	1974
Average starter response	4*	2	7*	8**	13**
Average percent N in leaves	—	2.7	2.7	2.8	2.8
Average K soil test	270	350	490	360	260
Average percent K in leaves	1.70	1.88	1.83	1.93	1.94
Average soil pH	7.7	7.2	7.3	7.4	7.1
Average Zn leaves (ppm)	18	17	27	22	30
Average Zn soil (ppm)	—	5.3	—	—	12

**significant at 1 percent.
*significant at 5 percent.
+significant at 10 percent.

Table 2. 1970 through 1974 corn yields, plant analyses, and soil tests in *Waseca County* according to broadcast *phosphorus* treatment

P_2O_5	Yields bu/acre					Percent P leaves					Soil test P lbs/acre				
lbs/A	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974
0	133	139	140	167	98	.29	.28	.29	.26	.32	34	27	39	36	28
50	136	133	142	164	99	.29	.27	.30	.28	.34	31	33	62	58	37
100	132	132	144	163	108	.28	.27	.32	.27	.36	31	40	91	62	63
150	136	135	141	162	104	.30	.30	.36	.28	.38	40	44	87	66	85
200	138	130	144	167	106	.31	.30	.34	.29	.38	53	45	79	76	96
	ns	ns	ns	ns	ns	ns	ns	**	ns	**					

	1970	1971	1972	1973	1974
Average starter response	13*	4	4	2	2
Average percent N in leaves	—	2.8	2.5	2.6	—
Average K soil test	310	280	390	380	300
Average percent K in leaves	1.79	1.82	1.88	2.28	2.57
Average soil pH	6.4	6.1	6.1	6.0	6.0
Average Zn leaves (ppm)	26	16	22	26	25
Average Zn soil (ppm)	—	2.6	—	—	5.7

**significant at 1 percent.
*significant at 5 percent.

Table 3. 1970 through 1974 corn yields, plant analyses, and soil tests in *Martin County* according to broadcast *potassium* treatment

K_2O	Yields bu/acre					Percent K leaves					Soil test K lbs/acre				
lbs/A	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974
0	156	148	120	160	148	1.7	1.8	1.6	1.8	2.1	202	230	295	273	160
50	147	154	127	155	148	1.7	1.8	1.7	1.9	2.2	212	258	360	303	245
100	152	149	129	157	153	1.8	1.9	1.8	2.2	2.6	222	278	328	318	275
200	147	143	130	151	151	1.6	2.1	1.9	2.1	2.2	270	328	415	380	290
400	160	149	132	158	149	1.6	2.1	1.9	2.2	2.6	243	320	490	533	375
	ns	ns	+	ns	ns	ns	**	**	**	ns					

	1970	1971	1972	1973	1974
Average starter response	16**	3	1	9**	8*
Average percent N in leaves	—	2.8	2.8	2.8	3.2
Average P soil test	50	62	99	68	71
Average percent P in leaves	.26	.28	.40	.27	.34
Average soil pH	6.4	6.1	6.1	6.1	6.4
Average Zn leaves (ppm)	22	22	30	26	40
Average Zn soil (ppm)	—	8.4	—	—	13

**significant at 1 percent.
*significant at 5 percent.
+significant at 10 percent.

Table 4. 1970 through 1974 corn yields, plant analyses, and soil tests in *Waseca County* according to broadcast *potassium* treatment

K_2O	Yields bu/acre					Percent K leaves					Soil test K lbs/acre				
lbs/A	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974
0	134	123	136	154	98	1.6	1.4	1.4	1.5	2.0	260	210	282	255	210
50	129	120	138	156	106	1.7	1.7	1.5	1.8	2.3	275	213	322	287	223
100	139	131	139	160	102	1.7	1.7	1.7	2.0	2.6	260	220	318	295	280
200	132	116	141	161	102	1.8	1.8	1.9	2.2	2.6	262	223	352	330	320
400	134	120	143	162	106	2.2	1.9	2.1	2.5	2.9	312	310	478	455	398
	ns	ns	ns	+	ns	**	**	**	**	**					

	1970	1971	1972	1973	1974
Average starter response	10*	7*	4	3	5
Average percent N in leaves	—	2.7	2.6	2.6	—
Average P soil test	53	52	79	76	63
Average percent P in leaves	.27	.31	.36	.28	.34
Average soil pH	6.4	6.0	6.0	5.9	5.7
Average Zn leaves (ppm)	25	14	24	28	33
Average Zn soil (ppm)	—	3.0	—	—	5.8

**significant at 1 percent.
*significant at 5 percent.
+significant at 10 percent.

Table 5. Row fertilizer[1] responses from phosphorus and potassium experiments in *Martin* and Waseca *Counties*, 1970 to 1974

County	Experiment	Years				
		1970	1971	1972	1973	1974
		bu/A				
Martin	P	4*	2	7*	8**	13**
	K	16*	3	1	9**	8*
Waseca	P	13*	4	4	2	2
	K	10*	7*	4	3	5

[1]Total row fertilizer each year was 10 + 40 + 40 per acre in Martin County and 13 + 34 + 45 per acre in Waseca County of N, P_2O_5, and K_2O, respectively.

**significant at 1 percent.
*significant at 5 percent.

averaged from 8 replications in Martin and Waseca Counties, respectively. There were no significant P treatment effects at the 95 percent level of significance during the experiment.

Soil test P in the check plots did not appear to decline during the 5 years of the trial. In every case except two, all P tests were above 30 pounds per acre of extractable phosphorus (the designated break between high and very high).

Soil tests related directly to P treatments, with a general increase in test levels from treatments during the course of the experiment. Some P tests approached or reached 100 pounds per acre of extractable P during the last year.

Broadcast potassium effect

The initial soil test K at the Martin County and Waseca County sites was 280 and 260 in exchangeable K, respectively (tables 3 & 4). These tests are high to very high. The soil test values in check plots were variable by years—sometimes as low as 210, and other years as high as 295. These are relatively high levels.

There were no significant yield increases from broadcast K at the 95 percent level of confidence in any of the years of the trials. However at Waseca in 1973, there was a significant K response at the 90 percent level of confidence (table 4).

At both locations, soil test K on the check plots was generally lower the 5th year of the experiment. This may indicate a decline in exchangeable K after 5 years; however, the levels were not low enough to show a yield response from any of the K treatments or low levels in the plant tissue. Tests made at the Martin County check plots in October 1975 averaged 245 pounds per acre of exchangeable K; hence 1974 readings were probably not a true indication of a soil test level decline over the 5 years.

Row treatment effect

Each P and K experiment had 5 treatments and 8 replications, or 40 plots. Since each was split, there were 40 plots with row fertilizer and 40 without in each of the P and K experiments at the two county locations. There was evidence that row fertilizer will give a response where broadcast applications do not. This was not consistent, however. Responses to row fertilizer were more frequent on the Martin County plots than at the Waseca location (table 5). Considering that the P experiments were separate from the K trials, there were two trials each year for 5 years or 10 trials over 5 years at each location. In Martin County, there was a significant response in 7 out of 10 trials, but only in 3 out of 10 in Waseca County. Many of the yield increases due to row treatment were quite small and would not have been economical.

There was no broadcast versus row application interaction, indicating that a row response was just as likely on a high broadcast treatment plot as on a no broadcast plot area.

Plant analyses

Results from plant analyses are shown in appendix tables 2 to 21. Examination of these data shows frequent significant treatment effect on plant content in contrast to no effect on yield.

In Waseca County, broadcast K had a highly significant effect on K in the leaves all 5 years of the study (table 4) and three out of five years in Martin County (table 3). The K treatment frequently caused a highly significant increase in K content and a correspondingly significant decrease in magnesium (appendix tables 5, 8, 9, 12, 13, 14, 16, 17, 21). Magnesium levels, however, always remained above the safe level. The effect of broadcast P was less, showing a highly significant effect in 2 of 5 years in Waseca County (table 2) and a significant effect only once in 5 years in Martin County (table 1). The P treatment caused a significant decrease in Zn content, but not below threshhold levels (appendix tables 10, 11, 14, 18, 19). In all years except 1974, K content in leaves of K check plots in Waseca County were below 1.7 percent, the threshhold level for corn. However, there were no significant yield increases.

Plant tissue Zn levels were low in 1971 at both locations, with no significant effect from P or K treatments. In 1972 to 1974, broadcast treatments of both P and K showed a significant effect on Zn levels, but lowest levels were usually in the sufficient range which would indicate a doubtful effect of these levels on corn yield.

In 1971 at Waseca, boron leaf tests bordered on low (appendix table 7). In 1972, boron treatments were made on four of the eight replications. No yield effect from these treatments was noted, but higher boron readings in

leaf tissue were observed across all treatments. Drouth stress at the time of leaf sampling in 1971 perhaps caused the low boron readings.

Some years, below borderline readings of other nutrients were also observed. These were apparently weather-related, as higher readings were measured in subsequent years.

Nitrogen content in leaves was not measured for all P and K treatments each year; therefore, this nutrient was not included in the statistical analyses. Usually Kjeldahl N was determined across all broadcast treatments for two replications.

Average N content for both experimental sites ranged from 2.78 to 2.83, except in Waseca County where values averaged 2.55 and 2.61 in 1972 and 1973, respectively. These levels were considered to be adequate.

Summary

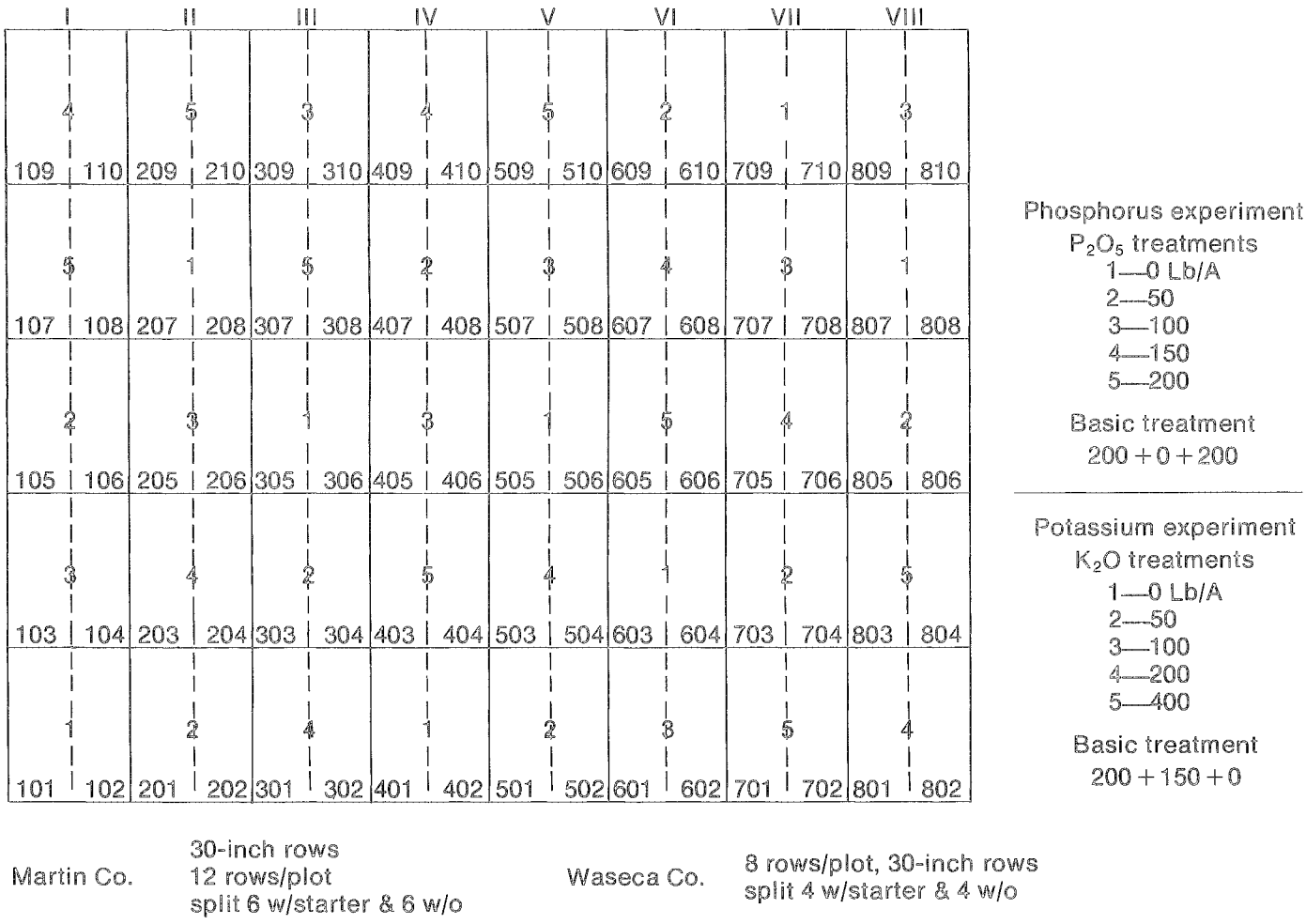
Experiments were conducted with broadcast applications of P and K for corn on soils testing high in these plant nutrients. Row fertilizer was superimposed, using a split-plot design on the broadcast treatments to observe whether higher yields could be obtained from this practice. Nitrogen was added to all plots.

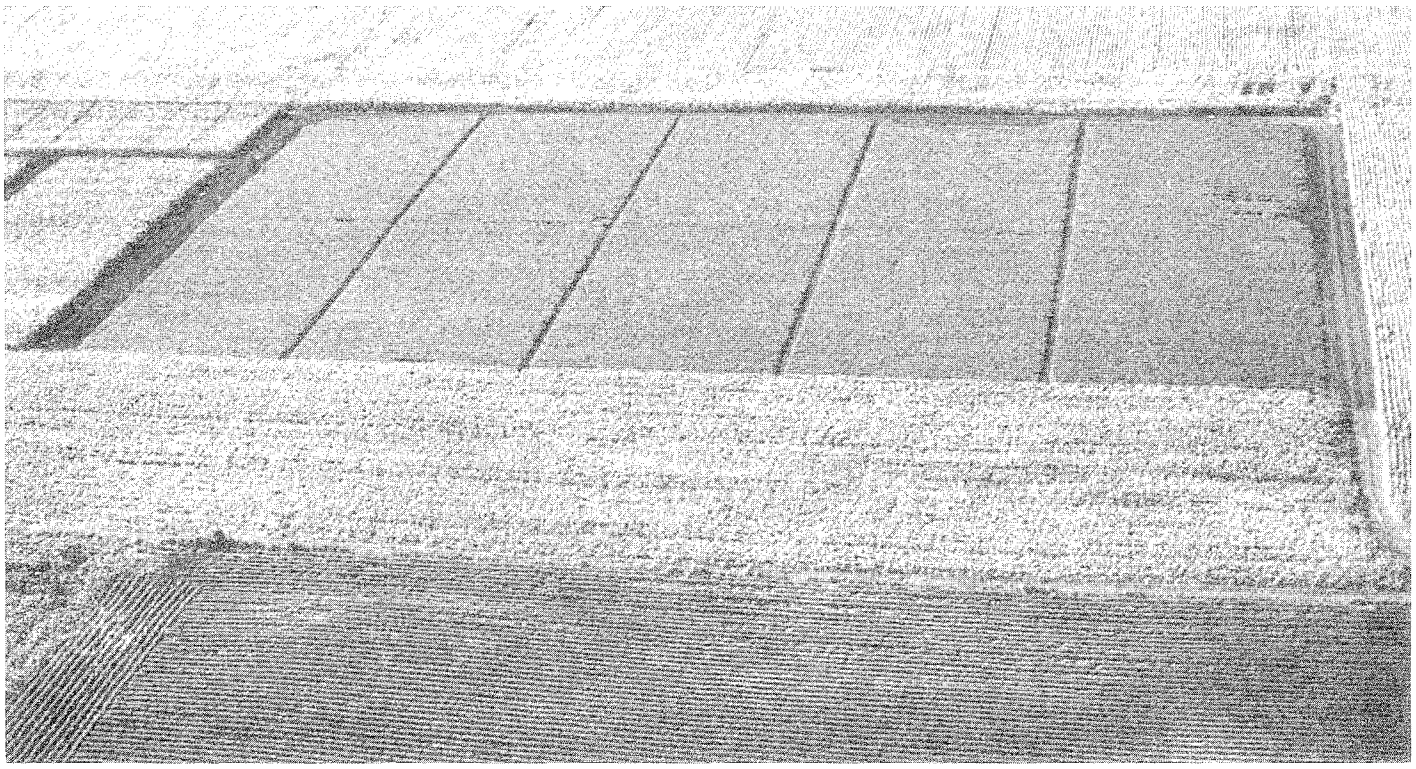
Data from these trials over 5 years suggest these conclusions:

1. When soil tests were very high in extractable P and high in exchangeable K, broadcasting added P and K had little, if any, effect on corn yields during the 5 years of this experiment.
2. Row fertilizer showed occasional significant responses, where broadcast treatments did not.
3. The frequency of significant row fertilizer response on high testing soils occured about 50 percent of the time; this response probably happens when weather causes cold soil conditions in the early growing season.
4. Plant analyses showed significant effect from P and K treatments; however, this was not reflected in yield increases.

APPENDIX

Appendix Figure 1. Plot layout for both P and K experiments on continuous corn in Martin and Waseca Counties. Broken line represents division between starter and no-starter within broadcast treatments.





Appendix Figure 2. Aerial photo showing the P and K experimental site where soybeans were grown in 1975.

Appendix Table 1a. Precipitation by years at Fairmont for the growing season April through September

Month	1970	1971	1972	1973	1974
April	2.52	0.73	2.41	2.65	2.99
May	8.20	2.92	3.97	6.43	5.15
June	1.88	5.26	4.77	1.49	3.94
July	3.89	2.70	5.84	3.37	2.11
August	1.40	1.37	1.29	1.24	4.62
September	2.58	2.64	2.81	6.15	1.11
Total	20.47	15.62	21.09	21.33	19.92

Appendix Table 1b. Precipitation by years at the Waseca Experiment Station for the growing season April through September

Month	1970	1971	1972	1973	1974
April	3.27	1.32	2.57	4.66	2.47
May	4.43	3.17	4.28	6.26	3.67
June	3.29	5.33	1.69	3.40	4.78
July	6.36	2.76	7.74	4.65	1.94
August	0.79	0.47	1.53	5.77	5.42
September	3.62	1.62	5.32	4.27	1.01
Total	21.76	14.67	23.13	29.01	19.29

Appendix Table 2. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1970

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.26	1.69	.80	.36	114	20	8	57	11
No starter	.27	1.70	.80	.35	134	17	8	56	12
Significance:	ns	ns	ns	ns	*	ns	ns	ns	ns
BLSD	—	—	—	—	17	—	—	—	—
Broadcast treatment (lb. P_2O_5/A)									
0	.26	1.66	.81	.36	114	18	9	52	12
50	.26	1.70	.82	.34	141	18	8	59	10
100	.27	1.78	.80	.37	105	18	8	53	12
150	.28	1.70	.81	.35	127	19	8	58	12
200	.28	1.63	.81	.34	133	18	7	58	12
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	5.9	9.4	7.3	15.2	39.8	6.7	14.9	14.3	12.5
Sufficient quantity[1]	.25	1.71	.21	.21	21	20	6	21	4

[1]J. Benton Jones and Harold V. Eck. Soil testing and plant analysis, Soil Science Society of America, Inc. 1973. The sufficient quantity values in succeeding tables 3 to 21 are from this reference.

*significant at 5 percent.
ns nonsignificant.

Appendix Table 3. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1970

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.30	1.65	.73	.43	96	25	7	45	7
No starter	.29	1.92	.70	.40	98	27	13	48	7
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
Broadcast treatment (lb. P_2O_5/A)									
0	.29	1.83	.69	.42	95	26	15	45	7
50	.29	1.61	.73	.41	97	27	11	53	6
100	.28	1.80	.71	.43	94	30	7	45	7
150	.30	1.74	.76	.43	93	22	8	43	7
200	.31	1.95	.69	.40	107	27	9	48	7
Significance:	ns	*	ns	ns	ns	ns	ns	ns	ns
BLSD	—	.23	—	—	—	—	—	—	—
CV	6.7	11.2	9.7	13.2	12.5	26.6	76.5	34.2	13.6
Sufficient quantity[1]	.25	1.71	.21	.21	21	20	6	21	4

[1]J. Benton Jones and Harold V. Eck. Soil testing and plant analysis, Soil Science Society of America, Inc. 1973. The sufficient quantity values in succeeding tables 3 to 21 are from this reference.

*significant at 5 percent.
ns nonsignificant.

Appendix Table 4. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1970

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.26	1.63	.80	.34	111	24	7	57	11
No starter	.26	1.76	.81	.32	113	20	7	58	12
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
Broadcast treatment (lb. K_2O/A)									
0	.26	1.69	.78	.31	102	19	5	46	12
50	.26	1.74	.82	.35	110	25	7	60	11
100	.27	1.80	.81	.31	112	25	9	62	12
200	.26	1.63	.83	.35	108	23	6	59	12
400	.25	1.63	.80	.33	127	20	6	61	11
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	8.6	7.9	11.8	18.3	18.4	30.9	35.6	33.0	10.5
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

ns nonsignificant.

Appendix Table 5. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1970

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.31	1.74	.80	.50	99	26	6	52	7
No starter	.30	1.78	.75	.47	95	23	6	43	7
Significance:	ns	ns	ns	ns	ns	ns	ns	*	ns
BLSD	—	—	—	—	—	—	—	7	—
Broadcast treatment (lb. K_2O/A)									
0	.32	1.55	.87	.58	105	26	9	57	8
50	.30	1.67	.77	.49	103	25	7	45	7
100	.32	1.66	.79	.49	95	24	6	47	7
200	.29	1.75	.72	.48	92	26	4	47	7
400	.29	2.17	.72	.39	89	21	4	42	6
Significance:	ns	**	**	*	*	ns	**	*	ns
BLSD	—	.30	.07	.10	12	—	2	10	—
CV	12.4	16.6	8.7	18.9	11.3	20.8	41.5	18.3	17.8
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 6. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1971

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.29	1.88	.60	.31	131	16	8	46	9
No starter	.28	1.89	.62	.33	138	18	8	49	8
Significance:	ns	ns	ns	ns	*	ns	ns	ns	ns
BLSD	—	—	—	—	5	—	—	—	—
Broadcast treatment (lb. P_2O_5/A)									
0	.28	1.90	.62	.31	136	17	9	45	8
50	.27	1.89	.60	.33	140	19	8	46	8
100	.30	1.85	.62	.32	129	16	8	47	8
150	.30	1.95	.60	.31	132	16	7	50	9
200	.28	1.85	.61	.33	134	17	8	50	9
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	9.2	6.9	5.9	10.6	6.0	12.3	16.8	12.4	10.7
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

* significant at 5 percent.
ns nonsignificant.

Appendix Table 7. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1971

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.28	1.82	.54	.29	104	2	5	51	5
No starter	.28	1.82	.54	.27	102	2	5	52	5
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
Broadcast treatment (lb. P_2O_5/A)									
0	.28	1.75	.53	.30	100	16	5	51	5
50	.27	1.88	.51	.25	105	16	5	54	6
100	.27	1.78	.56	.30	104	16	5	70	5
150	.30	1.82	.55	.28	104	13	5	30	6
200	.30	1.87	.56	.27	101	15	5	52	4
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	10.9	6.5	8.5	11.9	7.8	11.9	64.0	51.1	63.1
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

ns nonsignificant.

Appendix Table 8. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1971

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.29	1.96	.61	.27	133	21	5	57	8
No starter	.28	1.93	.63	.31	136	23	6	55	8
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
Broadcast treatment (lb. K_2O/A)									
0	.28	1.82	.64	.33	138	22	6	58	8
50	.30	1.79	.65	.34	136	20	6	57	8
100	.28	1.94	.61	.27	131	22	5	57	8
200	.28	2.09	.59	.26	134	21	5	48	8
400	.28	2.07	.61	.26	135	25	6	60	8
Significance:	ns	**	*	**	ns	ns	ns	ns	ns
BLSD	—	.16	.05	.03	—	—	—	—	—
CV	9.3	7.8	6.8	12.0	6.5	23.3	18.2	15.0	10.5
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 9. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1971

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.30	1.70	.57	.33	113	13	5	42	6
No starter	.32	1.65	.57	.33	109	14	5	43	6
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
Broadcast treatment (lb. K_2O/A)									
0	.32	1.39	.64	.42	115	14	6	52	6
50	.31	1.66	.58	.34	116	14	6	43	6
100	.32	1.67	.59	.33	107	14	5	43	6
200	.29	1.75	.54	.31	112	14	5	39	5
400	.30	1.90	.50	.24	105	13	5	35	5
Significance:	ns	**	**	**	ns	ns	*	*	**
BLSD (.05)	—	.13	.04	.05	—	—	.8	11	.7
CV	9.2	8.3	7.8	14.4	9.2	19.0	14.3	22.7	12.6
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 10. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1972

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.40	1.80	.67	.27	139	27	8	53	7
No starter	.37	1.85	.65	.27	156	28	9	56	7
Significance:	*	ns	ns	ns	ns	ns	ns	*	ns
BLSD	.02	—	—	—	—	—	—	3	—
Broadcast treatment (lb. P_2O_5/A)									
0	.37	1.85	.64	.26	136	31	10	54	7
50	.39	1.87	.69	.28	161	28	8	62	7
100	.40	1.82	.66	.25	119	26	8	50	7
150	.39	1.76	.66	.28	173	26	8	52	7
200	.38	1.81	.67	.28	148	26	8	56	7
Significance:	ns	ns	ns	ns	ns	*	ns	ns	ns
BLSD (.05)	—	—	—	—	—	4	—	—	—
CV	8.5	6.2	11.0	14.4	35.5	13.7	16.5	16.6	6.8
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

* significant at 5 percent.
ns nonsignificant.

Appendix Table 11. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1972

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.33	1.92	.69	.39	104	21	8	43	7
No starter	.32	1.83	.69	.39	99	23	8	40	8
Significance:	ns	ns	ns	ns	ns	ns	ns	*	ns
BLSD	—	—	—	—	—	—	—	2	—
Broadcast treatment (lb. P_2O_5/A)									
0	.29	1.79	.64	.38	94	25	8	39	7
50	.30	1.88	.67	.36	97	23	8	48	7
100	.32	1.84	.70	.41	103	23	7	41	7
150	.36	1.88	.75	.40	107	19	8	38	8
200	.34	1.99	.71	.38	107	22	8	43	8
Significance:	**	ns	**	ns	**	*	ns	ns	ns
BLSD	.02	—	.05	—	8	4	—	—	—
CV	7.8	9.0	7.1	12.4	7.5	16.8	14.2	29.2	9.4
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 12. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1972

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.41	1.74	.71	.28	125	31	6	68	7
No starter	.38	1.81	.69	.28	124	30	7	68	7
Significance:	**	ns	ns	ns	ns	ns	ns	ns	ns
BLSD	.02	—	—	—	—	—	—	—	—
Broadcast treatment (lb. K_2O/A)									
0	.40	1.62	.74	.33	126	30	6	72	8
50	.40	1.67	.73	.31	121	28	7	65	7
100	.40	1.82	.70	.27	125	32	6	78	7
200	.40	1.87	.67	.25	130	28	6	62	8
400	.39	1.91	.65	.25	125	33	7	68	7
Significance:	ns	**	ns	*	ns	ns	ns	*	ns
BLSD	—	.17	—	.05	—	—	—	14	—
CV	7.4	9.3	11.5	16.8	5.5	16.4	20.7	17.9	9.4
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

** significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 13. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1972

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.36	1.75	.74	.44	121	23	7	50	8
No starter	.35	1.70	.74	.48	120	25	8	48	8
Significance:	ns	ns	ns	ns	ns	**	ns	ns	ns
BLSD	—	—	—	—	—	1	—	—	—
Broadcast treatment (lb. K_2O/A)									
0	.35	1.39	.82	.58	125	26	8	59	8
50	.36	1.50	.78	.53	122	24	7	49	8
100	.36	1.70	.74	.47	119	25	7	48	8
200	.34	1.90	.71	.38	120	26	7	51	8
400	.36	2.11	.65	.33	117	21	8	35	8
Significance:	ns	**	**	**	ns	*	ns	**	ns
BLSD	—	.16	.06	.05	—	4	—	9	—
CV	8.2	10.1	7.9	11.0	9.2	13.3	12.1	19.2	7.7
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

** significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 14. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1973

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.28	1.96	.73	.34	150	21	9	60	6
No starter	.29	1.89	.73	.32	161	23	10	65	6
Significance:	ns	ns	ns	ns	ns	*	ns	ns	ns
BLSD	—	—	—	—	—	2	—	—	—
Broadcast treatment (lb. P_2O_5/A)									
0	.27	1.96	.69	.33	155	26	10	55	6
50	.27	1.91	.75	.34	164	23	10	66	6
100	.29	1.92	.76	.29	157	21	9	67	6
150	.29	1.97	.73	.34	151	20	9	63	6
200	.30	1.89	.72	.35	151	19	9	61	6
Significance:	*	ns	ns	*	ns	**	ns	ns	ns
BLSD	.02	—	—	.04	—	4	—	—	—
CV	6.1	10.1	7.9	11.0	10.0	15.4	12.9	15.7	21.6
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

** significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 15. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1973

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.28	2.29	.73	.33	156	26	18	46	13
No starter	.28	2.27	.72	.32	156	26	16	40	12
Significance:	ns	ns	ns	ns	ns	ns	ns	ns	ns
Broadcast treatment (lb. P_2O_5/A)									
0	.26	2.23	.68	.32	149	27	22	40	12
50	.28	2.30	.71	.31	156	28	11	51	12
100	.27	2.31	.74	.33	162	28	26	46	13
150	.28	2.24	.77	.33	153	22	14	38	13
200	.29	2.32	.74	.32	161	25	14	39	12
Significance:	ns	ns	*	ns	ns	ns	ns	ns	ns
BLSD	—	—	.07	—	—	—	—	—	—
CV	9.1	6.9	8.2	12.7	6.4	30.0	76.5	28.0	19.7
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

* significant at 5 percent.
ns nonsignificant.

Appendix Table 16. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1973

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.28	2.12	.71	.28	150	25	7	78	5
No starter	.26	1.95	.72	.27	138	27	8	78	6
Significance:	ns	*	ns	ns	**	ns	**	ns	ns
BLSD		.11	—	—	5	—	.5	—	—
Broadcast treatment (lb. K_2O/A)									
0	.27	1.83	.77	.33	151	29	8	84	6
50	.28	1.88	.74	.30	143	22	7	73	5
100	.27	2.20	.68	.26	146	27	7	83	5
200	.28	2.07	.70	.24	147	25	8	75	6
400	.27	2.18	.68	.23	134	29	8	75	5
Significance:	ns	**	*	**	*	ns	ns	ns	ns
BLSD	—	.21	.08	.03	10	—	—	—	—
CV	6.3	10.0	9.6	12.3	6.3	28.2	10.3	18.0	18.1
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 17. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1973

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.28	2.03	.77	.41	156	25	23	44	14
No starter	.28	1.91	.79	.44	160	30	27	51	14
Significance:	ns	ns	ns	ns	ns	**	ns	ns	ns
BLSD	—	—	—	—	—	2	—	—	—
Broadcast treatment (lb. K_2O/A)									
0	.30	1.49	.93	.57	166	36	15	60	14
50	.28	1.75	.82	.50	163	29	35	52	15
100	.28	2.02	.77	.41	156	27	17	39	12
200	.28	2.15	.74	.38	158	26	25	47	14
400	.28	2.45	.64	.28	149	19	37	40	14
Significance:	ns	**	**	**	ns	**	ns	*	ns
BLSD	—	.10	.06	.03	—	8	—	16	—
CV	6.1	9.9	7.8	13.4	10.5	26.1	130.5	29.2	22.9
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 18. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1974

Treatment (lb. P_2O_5/A)	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
0	.30	1.80	.83	.46	232	36	13	79	9
50	.33	1.94	.84	.47	252	29	12	86	10
100	.34	1.92	.93	.49	215	25	11	73	10
150	.35	1.93	.90	.48	246	29	11	91	11
200	.37	2.11	.88	.47	226	25	10	75	12
Significance:	*	ns	*	ns	ns	*	ns	ns	ns
BLSD	—	—	.05	—	—	7	—	—	—
CV	7.2	14.0	2.1	5.9	16.0	8.2	13.9	13.9	8.0
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

* significant at 5 percent.
ns nonsignificant.

Appendix Table 19. The effect of phosphorus treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1974

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.37	2.63	.86	.35	302	27	10	56	14
No starter	.35	2.50	.84	.40	290	23	11	47	14
Significance:	**	*	ns	ns	ns	ns	ns	ns	ns
BLSD	.01	.13	—	—	—	—	—	—	—
Broadcast treatment (lb. P_2O_5/A)									
0	.32	2.62	.75	.34	297	29	12	49	13
50	.34	2.63	.82	.38	303	26	11	47	14
100	.36	2.55	.84	.36	293	26	11	60	14
150	.38	2.68	.90	.37	297	23	9	49	14
200	.38	2.37	.95	.41	289	20	10	55	14
Significance:	**	*	**	ns	ns	ns	*	ns	ns
BLSD	.03	.22	.04	—	—	—	2	—	—
CV	9.3	7.5	5.4	13.9	7.1	39.4	14.2	33.8	10.7
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

**significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 20. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Martin County, 1974

Treatment (lb. K_2O/A)	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
0	.33	2.10	.96	.46	234	45	11	109	10
50	.36	2.19	.87	.40	229	29	10	79	11
100	.33	2.55	.81	.31	229	47	11	104	9
200	.35	2.18	.88	.30	236	33	12	89	11
400	.31	2.59	.77	.28	224	47	11	98	9
Significance:	ns	ns	*	**	ns	**	ns	ns	ns
BLSD	—	—	.10	.06	—	8	—	—	—
CV	3.4	6.0	4.3	6.5	1.7	7.2	16.9	21.4	9.7
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

** significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

Appendix Table 21. The effect of potassium treatments on 9 nutrients in the 6th leaf of corn taken at silking in Waseca County, 1974

Treatment	P	K	Ca	Mg	Fe	Zn	Cu	Mn	B
	percent				ppm				
Starter	.34	2.53	.84	.39	293	34	9	55	15
No starter	.34	2.40	.84	.45	306	33	10	51	15
Significance:	ns	ns	ns	*	ns	ns	ns	ns	ns
BLSD	—	—	—	.05	—	—	—	—	—
Broadcast treatment (lb. K_2O/A)									
0	.34	2.03	.92	.55	307	38	9	64	15
50	.34	2.29	.90	.44	294	37	9	60	15
100	.35	2.56	.85	.41	296	34	10	55	15
200	.34	2.59	.79	.35	283	27	9	40	14
400	.35	2.86	.75	.33	315	30	9	45	15
Significance:	ns	**	**	**	ns	ns	ns	*	ns
BLSD	—	.25	.05	.06	—	—	—	15	—
CV	6.3	10.6	5.8	14.9	14.4	24.9	11.5	26.3	9.9
Sufficient quantity	.25	1.71	.21	.21	21	20	6	21	4

** significant at 1 percent.
* significant at 5 percent.
ns nonsignificant.

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