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NUTRITIONAL STUDIES WITH CORN

by

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INTRODUCTION

At the end of nineteenth century, modern research on mineral nutrition of corn apparently originated in Germany. Since then a wide research effort has been made in this country and a large amount of literature has accumulated with facts concerning the nutrient requirements for this vital crop.

Corn is important as food for man and feed for the animal. With the advance of modern techniques wide number of industrial products are obtained from this field crop. Early chronicles cite corn as the most important plant cultivated by the Indians of ancient America. The corn growing areas extended westward to the middle of Kansas and Nebraska, part of Arizona, New Mexico and southern Colorado. During the nineteenth century the corn plant played an important role in the development in what is now Ohio, Indiana, Illinois and Iowa.

At the present time corn ranks as one of the leading crops of the world and this country alone plants annually over 80 million acres which constitute over one-half of the total world's supply. In 1950 about 25 per cent of all commercial fertilizer consumed in the United States were applied to corn. In Kansas, corn is grown extensively in the eastern third of the state. Corn is third in importance among the cultivated crops in the state and surpassed only by wheat and sorghum.

The investigation reported in this thesis was designed to study the relative uptake of nutrients by the corn plant from two levels of application of four phosphate containing fertilizers. Therefore the knowledge gained from this study may lead to better fertilizer practices for the future of this crop.

REVIEW OF LITERATURE

Tissue analysis as applied to corn plant has been used with emphasis in recent years as an index of the current nutrient level for this plant. Leaf analysis for example was utilized by Scarseth (22) to study nutrient uptake in a fertility experiment and also for the evaluation of fertilizer placement experiments.

Following this line of research Tyner (26) in 1946 established the critical lower limits for corn plant at about 2.90 per cent nitrogen, 0.295 per cent phosphorus, and 1.30 per cent potassium in the sixth leaf at tasseling time. This investigator reported that nutrient concentrations above these levels resulted in a doubtful or rapidly decreasing growth response. The critical lower levels for nitrogen as observed by B. G. Ellis (9) in Kansas were 3.0 %, 2.5 %, and 1.9 %, respectively, for corn when it was three feet in height, at tasseling and in the early ear stage.

The positive correlations found between leaf nitrogen and grain yield lead Tyner (26) in West Virginia to establish quantitative relations. He found for each change of 0.1 per cent nitrogen, phosphorus, and potassium in the sixth leaf at silking stage, yields changed 4.43, 25.3 and 2.05 bushels per acre, respectively. Bennett as quoted by Nelson (15) reported that each change of 0.1 per cent nitrogen was related to a yield change of 3.19 bushels in Iowa. In Washington Viets et al (27) found each 0.1 per cent of nitrogen to correspond to 5.53-6.99 bushels of corn.

The total accumulation of dry matter and mineral elements in corn in pounds per acre were observed by Sayre(21). Plants one month old accumulated 118 pounds dry matter; 3.5 pounds nitrogen; 0.3 pound phosphorus; 4.9 pounds potassium; 0.5 pound calcium and 0.2 pound magnesium. At the end of the growing season the recorded figures were: 6 tons, 144, 30, 112, 12 and 12 pounds per acre, respectively.

Sayre also reported losses of 15 pounds of potassium per acre from the plants, probably to the soil, at later stages of growth. On the contrary, Hanway (11) found potassium accumulation until a later stage of maturity and there was no loss of the element during that time of the season as reported by Sayre. Hanway believed the difference probably resulted because of a higher level of potassium availability in Sayre's study, potassium uptake during July was more rapid, and accumulation ceased early in the season, and thus the element was lost from the plants in the latter stage.

The effect of soil treatments and yield have received considerable attention. The investigations done by Smith (23, 24) on soils low in potassium and phosphorus in southeast Kansas showed an average increase in yield by the addition of potassium to corn, wheat, alfalfa and soybeans. But the greatest effect was observed on corn yield. He also recorded the response of corn to lime; lime and superphosphate; lime and rock superphosphate: lime, manure and superphosphate: lime, manure and rock phosphate: lime, superphosphate and potash over the years from 1931 to 1954 when yield le levels of 151, 165, 177, 179, 185, and 179 per cent, respectively, were observed in comparison with untreated soil rated as 100 per cent.

Bennett (1) reported increases in phosphorus content with addition of nitrogen. This effect in wheat and oats was studied by Olson (18) and he found that NH_4+ ion apparently exceeds NO_3^- in promoting phosphorus utilization especially during early stages of plant growth. Olson also reported the high efficiency associated with side-band placement of nitrogen plus phosphorus fertilizers in small grains (17).

Webb and Pesek (28) in Iowa obtained up to 90 per cent of the maximum increase of corn yield with starter fertilizers having 60% of the phosphorus in a water-soluble form with hill fertilization rates of 10 to 30 pounds per acre of available P205. They also reported (29) that the degree of water solubility of phosphorus had little influence on the effectiveness of fertilizers broadcast and plowed under for corn.

Brage et al (5) reported that urea with 2.5% biuret reduced stands of small grains by 30% when an equivalent of 20 pounds nitrogen per acre was applied to the seed. But urea with 10% biuret applied broadcast at 160 pounds nitrogen per acre and disced in before planting did not have significant effect on barley or corn stand. Smika and Smith (25) in 1957 attributed the toxicity of certain samples of commercial urea on germination to biuret.

The antagonistic effect of potassium on the absorption of magnesium by plants is known. Ellis (9) and Knauss (12) noted repression of magnesium content of corn leaves by addition of potassium in the fertilizer.

Results from Phillips (20) indicated that total potassium uptake is a more precise measurement of availability soil potassium than is the per cent of the element in the whole plant or in the sixth leaf. However, a linear relationship between the exchangeable potassium and the per cent of the element in leaf of corn was reported by Knauss (12).

Lucas et al (14) in Indiana stated that the per cent of nutrients in corn was influenced by soil type, soil treatment and season. Table 1 as given by Latshaw and Miller (13) provides a general idea of the concentration and number of major and minor elements in corn plant. Table 2 as reported by Newton (16) gives a comparative study between corn and other crops with respect to major elements.

Table 1. Weight of the elements that composed the stem, leaves, cob, grain, and roots of pride of Saline corn plants grown at Manhattan, Kansas, in 1920. (Average of five plants)

Average dry weight of stems, leaves, cob, grain, and roots, 835.9 g.	Weight, grams	Percentage of the total dry weight
Oxygen	371.4	44.431
Carbon	364.2	43.569
Hydrogen	52.2	6.244
Nitrogen	12.2	1.459
Phosphorus	1.7	0.203
Potassium	7.7	0.921
Calcium	1.9	0.227
Magnesium	1.5	0.179
Sulphur	1.4	1.167
Iron	0.7	0.083
Silicon	9.8	1.172
Aluminum	0.9	0.107
Chlorine	1.2	0.143
Manganese	0.3	0.035
Undetermined elements	7.8	0.933

Table 2. Percentage of the dry weight of:

Plant	Ca	K	Mg	N	P
Sunflower	2.2	5.0	0.64	3.6	0.59
Beans	2.1	4.0	0.59	3.6	0.55
Wheat	0.8	6.7	0.41	4.5	0.49
Barley	1.9	6.9	0.54	4.7	0.52
Peas	1.6	5.3	0.50	4.5	0.19
Corn	0.5	3.9	0.40	2.9	0.39

MATERIALS AND METHODS

Soil Description

Soils at Agronomy Farm and Ashland Agronomy Farm as described by Bidwell (3) are Geary silty clay loam and Sarpy fine sandy loam, respectively. The soil at Gerald Steely farm as described by Eikleberry (8) is Marshall silt loam. The following profile descriptions are given:

Geary Soil Series. Geary series consists of well drained moderately dark colored moderate to fine textured, Reddish Prairie soils, developed in reddish brown loess or loess-like materials believed to be of post Illinoian age. These soils occur in the transition belt between Chernozem and Prairie zones.

A_{1P} 0-3" Grayish brown (10 YR 5/1-5 dry); very dark gray (10 YR 2.5/1 moist, silty clay loam; moderate very fine granular structure; friable and slightly hard; non-calcareous; abrupt boundary; 3-8" thick.

A_{21} 3-8" Dark grayish brown (10 YR 4/1.5 dry), very dark gray (10 YR 2.5/1 moist), silty clay loam; moderate very fine sub-granular blocky structure; firm, hard, non-calcareous; clear boundary; 4-8" thick.

AB 8-14" Dark gray (10 YR 4/1 dry), very dark gray (10 YR 3/1 moist); silty clay loam; strong very fine sub-angular blocky structure; firm, extremely hard; non-calcareous; clear boundary; 4-8" thick.

B_{21} 14-30" Grayish brown (10 YR 5/2 dry), very dark grayish brown (10 YR 3/2 moist); silty clay; moderate medium blocky structure; very firm, very hard; non-calcareous; clear boundary; 10-15 " thick.

B_{22} 30-42" Brown and dark brown (10 YR 5/3 & 4/3 dry) and dark brown (10 YR 4/3 moist); silty clay; weak blocky structure; very firm, very hard; non-calcareous; clear boundary; 10-15" thick.

B_3 42-52" Pale brown and yellowish brown (10 YR 6/3, 5/4 dry), and (10 YR 5/3, 7·5 YR 4/4 moist); silty clay; many fine distinct mottles; massive structure; very firm, extremely hard; non-calcareous; clear boundary; 8-12" thick.

C 52-60" Pale brown and yellowish red (10 YR 6/3, 5 YR 4/7 dry), and (7·5 YR 5/4, 4/4 moist); silty clay; many fine distinct mottles; massive structure; firm, extremely hard; non-calcareous.

Topography - Nearly level to rolling relief on eroded uplands.

Drainage and Permeability:-Well drained; run-off medium; permeability moderately slow.

Use:- Highly productive soils when cultivated; occur in 30-32" rainfall belt in Kansas. They are well adapted to wheat, alfalfa, oats, grain sorghum and corn.

Distribution:- North central and northeastern Kansas and adjacent parts of Nebraska. Greatest extent along the Kansas River and its tributaries.

Sarpy Soil Series. This is a light colored, coarse textured, well drained, neutral to calcareous, alluvial soil of the Republican and Kansas River Valleys. It is sandy throughout the profile. Its surface color is grayish brown and the subsoil is pale brown.

A_1 0-20" Grayish brown (10 YR 5/1.5 dry), to dark grayish brown (10 YR 4/2, moist); loamy fine sand; massive structure; soft, very friable; calcareous; gradual boundary: 10-20" thick.

C 20-60" Pale brown (10 YR 6/3 dry) to grayish brown (10 YR 5/2 moist): loamy fine sand; single grain structure; soft, very friable; non-calcareous.

Permeability is very rapid. Run-off is slow, water table is within 8 feet on the surface. This soil is subject to periodic flooding.

Use:- Fertility is moderate. Crops grown are wheat, sorghum, alfalfa, corn and oats.

Marshall Series. The Marshall soils have formed from loess. They occur throughout the northeastern part of Brown County, and they have deep, silty surface soil and granular, friable subsoil. The underlying parent material is yellowish-brown silty clay loam.

A_p 0-6" Very dark grayish-brown (10 YR 3/2) silt loam; weak granular structure; soft, friable; clear, smooth boundary.

B_1 6-13" Very dark brown (10 YR 2/2) silt loam; moderate coarse granular structure; gradual boundary.

B_{21} 13-25" Very dark grayish-brown (10 YR 3/2) silty clay loam; weak irregular blocky to moderate coarse granular structure; friable; gradual boundary.

B_{22} 25-41" Dark-brown (10 YR 3/3) silty clay loam; coarse sub-angular blocky structure; friable; gradual boundary.

B_3 41-60" Dark yellowish-brown (10 YR 4/4) light silty clay loam; weak sub-angular blocky structure; friable; clear, smooth boundary.

C_1 60-70"+ Yellowish-brown (10 YR 5/4), friable, noncalcareous silt loam (leached loess).

Permeability is moderate. The slope is undulating to rolling.

Use:- Crops grown are corn, wheat, oats, legumes.

Chemical Analysis of Soils

Soil material on which corn was grown was analyzed using the standard test methods in the Kansas State Soil Testing Laboratory. The analyses included determinations of pH, lime requirement, available phosphorus, exchangeable potassium, and organic matter.

The pH values were measured by use of a Beckman glass electrode. Five ml. of distilled water were added to 5 g. of soil. The mixture was stirred, allowed to stand for 20 minutes, stirred again at intervals just before taking the final reading. Lime requirement on each sample was made by the use of Woodruff's buffer solution (30). For samples having pH values of 6.3 or less, 10 ml. of the buffer solution were added to each of these samples, stirred, allowed to stand for 30 minutes, stirred again and the pH readings finally taken. For every tenth of a pH unit under PH7.0 one thousand pounds of lime per acre was recommended.

Available phosphorus was determined by a modified Bray's sulfonic acid reduction colorimetric method. One g. of air dried soil was extracted with 10 ml. of extracting solution which was 0.025 N HCl plus .03 N NH_4 F. The amount of phosphorus in the filtrate was measured by means of a Coleman Junior Spectophotometer.

Exchangeable potassium of the soil was determined by shaking 10 g. of the soil in 50 ml. of 1 N NH_4 OAc for 10 minutes. After filtering, 20 ml. of this solution were added to 2 ml. of solution containing 1100 ppm lithium as lithium nitrate. The resulting solution was passed through a Perkin-Elmer flame photometer and content of potassium was determined by use of a standard curve.

Organic matter was determined (10) by taking one gram of soil and adding 10 ml. of 1 N potassium dichromate plus 20 ml. of concentrated sulfuric acid (Sp. gr. 1.84). The mixture was allowed to stand for 30 minutes and then 100 ml. of distilled water were added. Filtering the solution, a reading was made by use of a Coleman Junior Spectophotometer.

Table 3. Chemical properties of soils used in corn fertilizer trials, 1961.*

Experimental Location	pH	Lime requirement (lbs./A.)	Organic matter %	Available phosphorus (lbs./A.)	Exchangeable potassium (lbs./A.)
Gerald Steely Farm, Brown County	5.5	3,000	2.8	16	435
Agronomy Farm, Manhattan	5.9	2,000	2.2	20	445
Ashland Agronomy Farm, Manhattan	7.5	-----	0.4	55	502

*As listed in the Kansas State Fertilizer handbook, 1961 edition

Table 4. Characterization of phosphatic fertilizers used in 1961 trials with corn.*

Fertilizer	Manufacturer's Guaranteed Analysis	Characterization of phosphorus (P_2O_5 basis) Total** (%)	Available (%)	Water soluble (%)***
Ammonium phosphate-nitrate	30-10-0	10	10	10
Ammonium Polyphosphate	15-60-0	60.5	60.6	60.5
Commercial Ammonium Phosphate	11-48-0	50.40	49.05	42.9
Triple superphosphate	0-45-0	46.07	44.71	37.5

*As listed in the Kansas State Fertilizer Handbook, 1961 edition for ammonium phosphate-nitrate, ammonium polyphosphate and commercial ammonium phosphate. As listed in the Kansas State Fertilizer Handbook, 1959 edition for triple superphosphate.

**As measured by digestion in a mixture of HCl and HNO_3.

***Measured by placing one g. of fertilizer on filter paper and leaching with successive small portions of H_2O until filtrate measured 250 ml.

Ammonium nitrate (33.5% N) was used as supplementary N in this study. Three methods of applying fertilizers were used. Broadcast application made some time before planting. The second application was a combination of broadcasting before planting and sidebanding at planting. The third method involved only sidebanding at time of planting.

The fertilizer was banded $1\frac{1}{2}$ inches to the side and 2 inches below the seed of the Iron Age Planter. This machine was developed by A. B. Farquar Co. of York, Pennsylvania.

Experimental Design

Three locations were used in this study, two at Manhattan and one in Brown county. The soil test results, presented in Table 3 suggested that phosphorus was a major limiting nutrient element at both the Agronomy Farm and the Gerald Steely Farm.

Tables 5, 6 and 7 list the treatments given to fertility trials. They were designed to give comparison between four phosphate containing fertilizers (ammonium nitrate-phosphate (30-10-0), ammonium phosphate (11-48-0), triple superphosphate (0-45-0), and ammonium polyphosphate (15-60-0).

Table 5. Treatments for corn fertility plots at Agronomy Farm.

No.	Treatment (Pounds per acre)	Description
	$N-P_2O_5-K_2O$	
1	0-0-0	Check
2	80-0-0B	Nitrogen only - (80-0-0), Broadcast
3	120-0-0B	Nitrogen only - (120-0-0), Broadcast
4	80-27-0R	30-10-0- (80-27-0), Row
5	120-40-0R	30-10-0- (120-40-0), Row
6	80-27-0R	15-60-0 + 33.5-0-0- (80-27-0), Row
7	120-40-0R	15-60-0 + 33.5-0-0- (120-40-0), Row
8	80-27-0R	11-48-0 + 33.5-0-0- (80-27-0), Row
9	120-40-0R	11-48-0 + 33.5-0-0- (120-40-0), Row
10	80-27-0R	0-45-0 + 33.5-0-0- (80-27-0), Row
11	120-40-0R	0-45-0 + 33.5-0-0- (120-40-0), Row
12	80-27-0B	30-10-0- (80-27-0), Broadcast
13	120-40-0B	30-10-0- (120-40-0), Broadcast
14	6.7-27-0R + 73.3-0-0B	15-60-0- (6.7-27.7-0), Row + 33.5-0-0-(73.3-0-0)Broadcast
15	10-40-0R + 110-0-0B	15-60-0-(10-40-0), Row + 33.5-0-0-(110-0-0), Broadcast
16	6.1-27-0R + 73.9-0-0B	11-48-0-(6.1-27.7-0), Row + 33.5-0-0-(73.9-0-0) Broadcast
17	9.2-40-0R + 110.8-0-0B	11-48-0-(9.2-40-0), Row + 33.5-0-0-(110.8-0-0) Broadcast
18	0-27-0R + 80-0-0B	0-45-0-(0-27-0), Row + 33.5-0-0-(80-0-0) Broadcast
19	0-40-0R + 120-0-0B	0-45-0-(0-45-0), Row + 33.5-0-0-(120-0-0) Broadcast

Table 6. Treatments for corn fertility plots at Ashland Agronomy Farm.

No.	Treatment (Pounds per acre)	Description
	N-P_2O_5-K_2O	
1	0-0-0	Check
2	120-0-0B	Nitrogen only- (120-0-0), Broadcast
3	160-0-0B	Nitrogen only- (160-0-0), Broadcast
4	120-40-0R	30-10-0- (120-40-0), Row
5	160-53-0R	30-10-0- (160-53-0), Row
6	120-40-0R	15-60-0 + 33.5-0-0- (120-40-0), Row
7	160-53-0R	15-60-0 + 33.5-0-0- (160-53-0), Row
8	120-40-0R	11-48-0 + 33.5-0-0- (120-40-0), Row
9	160-53-0R	11-48-0 + 33.5-0-0- (160-53-0), Row
10	120-40-0R	0-45-0 + 33.5-0-0- (120-40-0), Row
11	160-53-0R	0-45-0 + 33.5-0-0- (160-53-0), Row
12	120-40-0B	30-10-0- (120-40-0), Broadcast
13	160-53-0B	30-10-0- (160-53-0), Broadcast
14	10-40-0R + 110-0-0B	15-60-0- (10-40-0), Row + 33.5-0-0-(110-0-0) Broadcast
15	13.3-53-0R + 146.7-0-0B	15-60-0-(13.3-53-0), Row + 33.5-0-0-(146.7-0-0) Broadcast
16	9.2-40-0R + 110.8-0-0B	11-48-0-(9.2-40-0), Row + 33.5-0-0-(110.8-0-0) Broadcast
17	12.3-53-0R + 147.7-0-0B	11-48-0-(12.3-53-0), Row + 33.5-0-0-(147.7-0-0) Broadcast
18	0-40-0R + 120-0-0B	0-45-0-(0-40-0), Row + 33.5-0-0-(120-0-0), Broadcast
19	0-53-0R + 160-0-0B	0-45-0-(0-53-0), Row + 33.5-0-0-(160-0-0), Broadcast

Table 7. Treatments for corn fertility plots at Gerald Steely Farm, Brown County

No.	Treatment (Pounds per acre) $N-P_2O_5-K_2O$	Description
1	0-0-0	Check
2	120-0-0R	Nitrogen only- (120-0-0), Row
3	80-27-0R	30-10-0- (80-27-0), Row
4	120-40-0R	30-10-0- (120-40-0), Row
5	80-27-0R	15-60-0 + 33.5-0-0- (80-27-0), Row
6	120-40-0R	15-60-0 + 33.5-0-0- (120-40-0), Row
7	80-27-0R	11-48-0 + 33.5-0-0- (80-27-0), Row
8	120-40-0R	11-48-0 + 33.5-0-0 (120-40-0), Row
9	80-27-0R	0-45-0 + 33.5-0-0- (80-27-0), Row
10	120-40-0R	0-45-0 + 33.5-0-0- (120-40-0), Row

Collection and Preparation of Plants for Analysis

Whole plants of the variety Kansas 1859 were collected at both locations in Manhattan. The variety United Hagie 3H56 was sampled at Gerald Steely Farm. Representative plants taken at random, were collected when they were about one month old.

After sampling, the whole plants were dried in a forced-draft oven at 70° C. for three to five days. Later, they were ground in a Wiley mill, and stored in stoppered bottles. The samples were dried again in an oven at 100° C. for 4 hours prior to weighing for analysis.

Chemical Analysis of Plant Material

Whole plants were analyzed for nitrogen, phosphorus and four metallic cations (K, Na, Ca and Mg). All determinations except nitrogen, were made using a wet digestion procedure on the plant material.

The digestion procedure is essentially that as described by Early (7). Two grams of the finely ground material were digested in a dilute mixture of water, perchloric and nitric acids.

Cations: The determination of calcium, potassium, magnesium and sodium in the plant digest was made photometrically by means of the Beckman flame photometer, model DU. A photomultiplier was used to increase the sensitivity of the instrument. The standard solutions used to calibrate the flame photometer had the same ratio of cations as the unknown solutions in order to reduce the cation interferences (2,4). The acids known to be present in the unknown solutions were added in equivalent amount to the standard solutions.

Nitrogen: The Kjeldahl-Gunning method (19) was used with slight modifications on one g. sample of the ground plant material.

Phosphorus: To determine the amount of phosphorus in the digested solution the molybdenum blue method as proposed by Bray (6) was used. Two ml. of aliquot of the digest was diluted to a volume of 100 ml. in volumetric flask. Two ml. each of $(NH_4)_2\ M_0O_4$-HCl solution and 1-amino-2-naphthol-2-sulfonic in solution with sodium sulfite and sodium bisulfite were added. After 15 minutes, the intensity of the color developed was measured by use of an Evelyn photoelectric colorimeter with a 660 mm. filter in place.

The per cent transmittancy was determined and compared to a curve made by employing known concentrations of potassium phosphate.

DISCUSSION OF RESULTS

Yield Data

Agronomy Farm:

Significant variation in yields of dry matter existed at the time of the initial sampling (Table 8). The highest yield at this sampling was produced with use ammonium phosphate-nitrate(80-27-0) as a treatment banded along the row. However, none of the other treatments banded along the row and containing phosphorus actually produced significantly less than the ammonium phosphate -nitrate treatment. The lowest yields were produced by unfertilized plants and by those simply fertilized with nitrogen (80-0-0 and 120-0-0). Yields of plant material produced by treatments involving the broadcasting of ammonium nitrate-phosphate fertilizer (80-27-0 or 120-40-0) were not significantly different from those produced by broadcasting only ammonium nitrate. In other words the inclusion of the relatively small amounts of phosphorus (27 or 40 pounds per acre of available P_2O_5) as part of a broadcast treatment was essentially ineffective in providing early growth stimulation. On the other hand banding only the phosphate containing fertilizer (11-48-0, 15-60-0, or 0-45-0) and broadcasting all or at least most of the nitrogen was just as effective in providing the early growth stimulation as was banding the entire nutrient applications.

Final grain yields (Table 8) generally did not reflect the early growth stimulations which were noticed where fertilizer containing phosphate was banded along the row. The unfertilized corn produced an average yield of 120.4 bushels per acre. None of the treatments produced significantly less. Only one (Treatment 9) produced significantly more than the control plots. For all practical purposes, it could be assumed that the soil of the Agronomy Farm supplied sufficient nitrogen and phosphorus for the needs of corn in 1961.

Ashland Agronomy Farm:

Early growth stimulation was noted at the Ashland Agronomy Farm (Table 9). Each fertilizer treatment resulted in significantly more growth than was produced on check plots. There was considerable inconsistency in the variations among the amounts of growth resulting from the various fertilizer treatments. In most cases the presence of phosphate in the fertilizer treatment resulted in significantly more growth than was noted where only nitrogen was used. There was evidence that phosphorus supplied by ammonium polyphosphate (Treatments 15 and 15) was not so effective as that supplied by either ammonium phosphate (Treatments 16 and 17) or that supplied by triple superphosphate (Treatments 18 and 19). Likewise the broadcasting of the phosphorus component in ammonium nitrate-phosphate fertilizer (Treatments 12 and 13) was not so effective in stimulating early growth as was the banding of the phosphate component in a number of the treatments (Treatments 5, 8, 9, 10, 11, 16, 17, 18 and 19).

Marked yield increases resulted from the use of fertilizer--especially from the use of nitrogen. Mere use of either 120 or 160 pounds per acre of nitrogen increased yields at least 80 to 90 bushels per acre. Only one treatment (Treatment 11) produced significantly more grain than was obtained with use of just 120 pounds of nitrogen. This treatment (160-53-0 R) included triple superphosphate as its source of phosphorus. Seemingly the phosphate component was not generally needed to increase yield of corn at the Ashland Agronomy Farm.

Gerald Steely Farm:

Marked early growth stimulation occurred at this location (Table 10). Banding of fertilizers containing phosphate (Treatments 3 to 10, inclusive) essentially doubled dry matter production by the time of the first sampling. There generally was not significant variation among the treatments involving phosphate insofar as this effect was concerned. Use of nitrogen alone was not significantly effective in this regard.

Grain yield increases at the Gerald Steely farm were significantly greater where phosphate was part of the treatment than where it was not included. Source of phosphate did not seem to influence significantly the amount of grain produced. Likewise the heavier rate of phosphorus (40 pounds per acre of available P_2O_5) was not significantly superior to the lower rate. In summarizing yield stimulations at this location, it might be said that the phosphorus component was totally responsible for yield effects noted. In this regard the beneficial effects amounted to at least 12 bushels per acre and in some cases to about 16 bushels per acre.

Table 8. Corn grain and dry matter yields, Agronomy Farm, Manhattan, 1961

No.	Treatment	Yield of Dry Matter[1] (grams)	Yield of Grain Bu./A
	N-P_2O_5, K_2O		
1	0-0-0	18.84	120.4
2	80-0-0 B	22.23	119.9
3	120-0-0 B	24.01	117.7
4	80-27-0 R	43.73	122.8
5	120-40-0 R	41.81	120.0
6	80-27-0 R	38.30	118.4
7	120-40-0 R	40.19	121.2
8	80-27-0 R	40.00	125.6
9	120-40-0 R	42.85	127.4
10	80-27-0 R	38.82	116.7
11	120-40-0 R	39.64	121.0
12	80-27-0 B	23.57	115.9
13	120-40-0 B	27.42	116.9
14	6.7-27-0 R + 73.3-0-0 B	36.24	124.2
15	10-40-0 R + 110-0-0 B	37.59	115.9
16	6.1-27-0 R + 73.9-0-0 B	39.03	122.7
17	9.2-40-0 R + 110.8-0-0 B	42.59	118.2
18	0.27-0 R + 80-0-0 B	39.91	119.8
19	0-40-0 R + 120-0-0 B	39.75	120.7
L.S.D. (.05)		6.45	6.7

[1]Each value represents the weight of 10 plants one month old (five replications of 10 plants each).

Table 9. Corn grain and dry matter yields, Ashland Agronomy Farm, Manhattan, 1961.

No.	Treatment	Yield of Dry Matter[1] (grams)	Yield of Grain Bu./A
	N-P_2O_5-K_2O		
1	0-0-0	41.89	49.2
2	120-0-0 B	56.82	131.3
3	160-0-0 B	53.48	139.4
4	120-40-0 R	67.70	133.8
5	160-53-0 R	84.88	144.0
6	120-40-0 R	61.83	123.5
7	160-53-0 R	59.70	133.5
8	120-40-0 R	82.97	134.1
9	160-53-0 R	79.06	136.3
10	120-40-0 R	72.71	138.1
11	160-53-0 R	76.15	144.7
12	120-40-0 B	64.21	126.0
13	160-53-0 B	69.26	134.7
14	10-40-0 R + 110-0-0 B	66.45	122.3
15	13.3-53-0 R + 146.7-0-0 B	68.90	136.3
16	0.2-40-0 R + 110.8-0-0 B	87.74	123.8
17	12.3-53-0 R + 147.7-0-0 B	97.85	142.8
18	0-40-0 R + 120-0-0 B	84.47	128.2
19	0-53-0 R + 160-0-0 B	81.23	134.4
L.S.D. (.05)		10.80	12.1

[1]Each value represents the weight of 10 plants one month old (five replications of 10 plants each).

Table 10. Corn grain and dry matter yields, Gerald Steely Farm, Brown County, 1961.

No.	Treatment	Yield of Dry Matter[1] (grams)	Yield of Grain Bu./A
	N-P_2O_5-K_2O		
1	0-0-0	14.92	120.4
2	120-0-0 R	17.76	118.0
3	80-27-0 R	30.51	134.8
4	120-40-0 R	30.97	135.0
5	80-27-0 R	32.01	134.8
6	120-40-0 R	25.09	136.4
7	80-27-0 R	30.72	132.6
8	120-40-0 R	31.40	137.0
9	80-27-0 R	30.11	133.0
10	120-40-0 R	29.86	132.2
L.S.D. (.05)		5.78	8.9

[1]Each value represents the weight of 10 plants one month old (five replications of 10 plants each).

Chemical Composition

Levels of nutrients contained in the rapidly growing corn plants are indicated in Tables 10 to 12, inclusive.

Nitrogen: Level of this element in the plant did not show such great variation according to treatment. In the case of plants produced at the Agronomy Farm, those obtained from the unfertilized plots had significantly less nitrogen than those receiving fertilizer. Even so there was a high level in the unfertilized plants (4.09 per cent). and since corn at this location did not show final yield response to the added nitrogen, it seems only proper to regard this level in the control plots as entirely adequate.

Corn produced at the Ashland Agronomy Farm responded quite remarkably to nitrogen addition (Table 9). It was interesting to note, therefore, the nitrogen status of corn plants at such an early stage as those were when collected for the analyses reported in Table 11. Obviously the level in the control plants (3.32 per cent N) was not nearly enough to insure high yields of grain at harvest. On the other hand a level of about 4.0 per cent as was present in many of the plants on the fertilized plots, was sufficient to bring about a gain of some 80 or more bushels per acre in the yield of corn.

Nitrogen level was very high in all treatments used at the Gerald Steely Farm (Table 12). Based on the assumption that about 4.0 per cent at this early growth stage is adequate to insure against later deficiency, it can be noted that even the control plots at this location were well above this level. The final grain yields at this farm did not reflect benefits from the addition of nitrogen.

In the case of both the Agronomy Farm and the Ashland Agronomy Farm, the highest levels of nitrogen were occasioned by the use of the heavier rate of the ammonium nitrate-phosphate fertilizer (30-10-0). This did not hold for the Steely Farm where the highest level of nitrogen in plants actually resulted where the lower rate of nitrogen

Table 11. Total mineral accumulation of corn, one month old (Agronomy Farm, Manhattan, 1961)

		Composition (Per Cent)[1]					
No.	Treatment	N	P	K	Mg	Ca	Na
1	0-0-0	4.09	.364	5.04	.284	.338	.0354
2	80-0-0 B	4.35	.382	5.31	.293	.335	.0352
3	120-0-0 B	4.37	.396	5.08	.292	.332	.0354
4	80-27-0 R	4.66	.477	4.95	.258	.312	.0352
5	120-40-0 R	4.89	.536	4.99	.237	.297	.0375
6	80-27-0 R	4.68	.470	5.19	.261	.310	.0368
7	120-40-0 R	4.70	.467	4.96	.250	.322	.0360
8	80-27-0 R	4.73	.464	5.20	.261	.299	.0361
9	120-40-0 R	4.70	.505	5.05	.269	.288	.0353
10	80-27-0 R	4.53	.456	4.89	.265	.310	.0366
11	120-40-0 R	4.70	.492	4.86	.255	.298	.0363
12	80-27-0 B	4.33	.360	4.66	.278	.340	.0336
13	120-40-0 B	4.40	.392	5.08	.281	.359	.0351
14	6.7-27-0 R + 73.3-0-0 B	4.32	.456	5.09	.281	.324	.0344
15	10-40-0 R + 110-0-0 B	4.60	.493	5.14	.261	.306	.0355
16	6.1-27-0 R + 73.9-0-0 B	4.30	.417	5.27	.274	.328	.0392
17	9.2-40-0 R + 110.8-0-0 B	4.52	.515	5.00	.275	.305	.0361
18	0-27-0 R + 80-0-0 B	4.21	.383	5.30	.265	.318	.0385
19	0-40-0 R + 120-0-0 B	4.37	.443	5.11	.273	.343	.0348
L.S.D. (.05)		0.171	.030		.024	.034	

[1]Each value reported is an average of 50 plants one month old (five replications of 10 plants each).

Table 12. Total mineral accumulation of corn, one month old (Ashland Agronomy Farm, Manhattan, 1961).

		Composition (Per Cent)[1]					
No.	Treatment	N	P	K	Mg	Ca	Na
1	0-0-0	3.32	.449	5.73	.210	.354	.0299
2	120-0-0 B	3.98	.472	6.07	.261	.382	.0327
3	160-0-0 B	3.91	.488	5.75	.256	.466	.0340
4	120-40-0 R	4.01	.528	5.79	.224	.368	.0318
5	160-53-0 R	4.23	.509	5.67	.199	.356	.0309
6	120-40-0 R	4.04	.516	5.55	.229	.434	.0326
7	160-53-0 R	4.15	.499	5.61	.222	.447	.0348
8	120-40-0 R	4.00	.548	5.54	.219	.344	.0338
9	160-53-0 R	4.02	.549	5.93	.213	.395	.0340
10	120-40-0 R	3.92	.505	5.74	.207	.365	.0321
11	160-53-0 R	3.93	.526	5.99	.221	.461	.0357
12	120-40-0 B	3.91	.480	6.02	.235	.408	.0335
13	160-53-0 B	4.04	.443	5.62	.248	.400	.0294
14	10-40-0 R + 110-0-0 B	4.07	.476	5.82	.232	.403	.0315
15	13.3-53-0 R + 146.7-0-0 B	3.75	.542	5.78	.228	.366	.0312
16	9.2-40-0 R + 110.8-0-0 B	4.14	.473	5.85	.217	.391	.0314
17	12.3-53-0 R + 147.7-0-0 B	4.03	.531	5.65	.224	.344	.0307
18	0-40-0 R + 120-0-0 B	4.05	.459	5.61	.221	.340	.0304
19	0-53-0 R + 160-0-0 B	4.04	.464	5.78	.205	.366	.0310
L.S.D. (.05)			.054				

[1]Each value reported is an average of 50 plants one month old (5 replications of 10 plants each).

Table 13. Total mineral accumulation of corn one month old (Gerald Steely Farm, Brown County, 1961)

		Composition (Per Cent)[1]					
No.	Treatments	N	P	K	Mg	Ca	Na
1	0-0-0	4.14	.292	5.69	.290	.455	.0351
2	120-0-0 R	4.75	.302	5.28	.292	.470	.0338
3	80-27-0 R	5.11	.430	5.35	.260	.396	.0346
4	120-40-0 R	5.17	.451	4.84	.254	.411	.0315
5	80-27-0 R	4.89	.425	5.34	.255	.378	.0300
6	120-40-0 R	5.12	.432	5.17	.254	.409	.0314
7	80-27-0 R	5.24	.413	5.22	.266	.392	.0323
8	120-40-0 R	5.17	.468	5.44	.258	.376	.0333
9	80-27-0 R	4.91	.410	5.31	.258	.401	.0348
10	120-40-0 R	5.04	.432	5.11	.257	.407	.0330
L.S.D. (.05)		.279	.106	.305	.016	.122	

[1]Each value reported is an average of 50 plants one month old (5 replications of 10 plants each).

was supplied a combination of ammonium nitrate and commercial ammonium phosphate (11-48-0).

Combining nitrogen and phosphorus seemed to have a beneficial effect on nitrogen accumulation by plants. Not only was this beneficial in terms of early plant growth as has already been noted in conjunction with the discussion of Tables 8, 9, and 10, it was also helpful in bringing about increased nitrogen accumulating in the plant, For example, plants produced at the Agronomy Farm and treated with nitrogen alone had either 4.35 or 4.37 per cent of this element, depending on rate of application. Those produced by treatments 4 to 11, inclusive, and by treatments 15 and 17 contained more nitrogen. Each of the latter involved a band application of phosphate. Treatments 12 and 13 which involved the broadcast application of the 30-10-0 fertilizer did not reflect this benefit from phosphate inclusion--presumably because the phosphate was not banded. At the Ashland Agronomy Farm there was a slight tendency for the same relationship to hold insofar as phosphorus effect was concerned but there was much less significance to the effect--probably because the unfertilized soil contained considerable available phosphorus (Table 3 for chemical availability and Tables 11 and 12 for actual percentage of phosphorus in plants from unfertilized soils at the Agonomy Farm and Ashland Agronomy Farm, respectively). The effect of banded phosphate on nitrogen accumulation was most noticeable at the Gerald Steely Farm. The effect was greater at this location than at either of the others because of low availability of phosphorus in the soil. The relatively lower availability in the soil was suggested both by soil test data (Table 1) and by phosphorus percentage in unfertilized plants (Table 12).

Phosphorus: Adding phosphate generally increased the level of phosphorus in corn plants. This was especially true where phosphate was banded along the row in conjunction with the entire nitrogen application. Where the ammonium nitrate-phosphate fertilizer (30-10-0) was broadcast, the phosphate portion seemed to effect little change in nitrogen percentage in corn produced at either the Agronomy Farm or at the Ashland

Agronomy Farm.

Corn did not produce extra grain at either the Agronomy Farm or the Ashland Agronomy Farm as a result of any phosphate treatment. Presumably the levels of phosphorus in unfertilized corn plants (0.364 at the Agronomy Farm and 0.44 at the Ashland Agronomy Farm) were sufficient to meet the plants needs in 1961. Also it seemed that the extra accumulation in plants produced on plots receiving phosphate fertilization at these two locations and the extra early season growth produced at these two locations as a result of phosphate stimulation were not necessary for greater grain production. On the other hand phosphorus nutrition as provided by the unfertilized Marshall soil (Gerald Steely Farm) did not seem to be adequate. Thus it would seem that the level of 0.292 per cent phosphorus (control plots) was insufficient as was the level of 0.302 per cent (nitrogen plots). Raising this level to 0.410 per cent or slightly more was quite adequate. Probably it would not have had to been quite so high as 0.410 per cent because at the Agronomy Farm the presence of 0.364 per cent in the plants of the control plots was sufficient for essentially maximum yield of grain.

Considering both yield data (Table 9) and phosphorus composition data (Table 12) for the Gerald Steely Farm, it would seem that source of phosphorus was not important in determining the final effects. Yieldwise, there were not significant differences which could be attributed to type of phosphate. Compositionwise, the same relationship among sources of phosphate seemed to persist. Based solely on weight of plant material at the time of the first sampling, the ammonium polyphosphate (Treatment 6) seemed to be somewhat inferior to other phosphorus sources, but only when banded at the lower rate.

The highest percentages of phosphorus in plant tissue were produced by use of the heavier rate of ammonium nitrate-phosphate (30±10-0) banded along the row in the case of the Agronomy Farm, by use of the heavier rate of a combination of ammonium nitrate and ammonium phosphate banded along the row at the Ashland Agronomy Farm and by the use of the higher rate of a combination of ammonium nitrate and ammonium phosphate banded along the row at the Gerald Steely Farm. These materials were not materially different than other in this regard, however.

Cations (Na, K, Ca and Mg): Sodium was not readily absorbed by corn plants. The amount present usually ranged from 0.03 to 0.035 per cent. The amount present was not significantly influenced by any of the fertilizer treatments. This would seem logical since so little Na was absorbed by corn and since none of the fertilizers would be expected to contain appreciable Na.

Potassium content of the corn plants was always quite high. This would be expected since the soils were well supplied with exchangeable K. Plant material produced at the Agronomy Farm and at the Ashland Agronomy Farm did not vary significantly in content of K as a result of fertilizer treatment. There was evidence that fertilizer treatment reduced the K content of corn at the Gerald Steely Farm. It would seem that the small amount of calcium contained in triple superphosphate and supplied by treatments 9 and 10 was not an important factor in reducing the percentage of K in corn plant tissue. It is difficult to explain the reduction of K content on the basis of dilution due to extra plant growth. Plants of treatment 2 (120-0-0) were not appreciably larger in size than were plants from the control plots, yet such contained significantly less K. Possibly the availability of ammonium (NH_4^+) to plants as provided by all treatments receiving fertilizer (2 to 10, inclusive) was a factor in causing the slight, though significant, reduction which was noted in the cases of plants produced on fertilized plots.

Potassium was more abundant than any of the other cations in the corn plant tissue.

Calcium content of the plant tissue tended to be relatively constant. For material produced at the Ashland Agronomy Farm, there was not significant variation among the percentages of Ca contained in plants. While some pairs of samples differed significantly in amounts of Ca at the Agronomy Farm, there was not too much evidence of important variation in the material produced at the Agronomy Farm. Essentially the same could be said with respect to material produced at the Gerald Steely Farm. It was interesting to note that material collected from the latter farm contained appreciably more Ca (percentage) than did that obtained from either of the locations near Manhattan. Possibly this was due to the fact that the plants from the Steely plots were appreciably smaller.

Magnesium behaved much like Ca. It did not vary significantly according to treatment at the Ashland Agronomy Farm. Magnesium did vary significantly at the other two locations. In the case of the material from the Agronomy Farm, that from both treatments 4 and 5 (both rates of 30-10-0 banded along the row) had especially low content of Mg. There would not seem to be any reason, associated with the nature of the fertilizer, why this would be true, however. Presumably none of the fertilizers supplied appreciable Mg. Magnesium content of all plots receiving phosphorus (treatments 3 to 10, inclusive) at the Gerald Steely Farm had less than those not receiving this element as part of the fertilizer treatment. Presumably this was due to a dilution effect caused by the extra growth of plant material on these phosphate-fertilized plots.

SUMMARY AND CONCLUSIONS

1. At the Agronomy Farm, corn did not show a yield response for any fertilizer treatment except possibly for treatment 9 (combination of ammonium nitrate and ammonium phosphate to supply 120 pounds of N and 40 pounds of available P_2O_5 per acre banded along the row.
2. Corn responded remarkably to application of nitrogen at the Ashland Agronomy Farm. Response ranged from about 80 to 90 bushels per acre depending on rate of nitrogen supplied. This corn did not respond to phosphate application, however.

3. Corn at the Gerald Steely Farm did not respond to nitrogen treatment. However, it did give marked response to phosphate banded along the row. This response amounted to some 12 to 16 bushels per acre depending on specific treatment. However, neither source of phosphorus nor rate of application had a significant effect on magnitude of yield response.
4. Early growth of corn showed remarkable growth response to fertilizer application. At both the Agronomy Farm and at the Gerald Steely Farm phosphate banded along the row was the major factor in causing this early season growth stimulation. At the Ashland Agronomy Farm, appreciable early season growth response occurred where nitrogen alone was used. However, there appeared to be an interaction between nitrogen and phosphorus because greater growth responses occurred where these two were combined than occurred where only nitrogen was used.
5. Nitrogen seemed to be sufficient in plant material at both the Agronomy Farm and at the Gerald Steely Farm. The presence of slightly more than 4 per cent nitrogen in unfertilized corn at these two locations was sufficient to insure good grain production. Actually the critical lower limit for nitrogen seemed to be less than 4 per cent because at the Ashland Agronomy Farm, corn having somewhat less than 4 per cent yielded quite well. Unfertilized corn having only 3.32 per cent nitrogen was quite nitrogen deficient.
6. Corn with 0.364 and 0.449 per cent phosphorus, respectively, on the unfertilized plots at the Agronomy Farm and at the Ashland Agronomy Farm, seemed to have a sufficiently high level of this element to meet the plants needs.
7. Corn at the Gerald Steely Farm which had only 0.292 per cent phosphorus at the time of the early sampling was inadequately supplied for later growth and development.
8. These last two conclusions were confirmed by the yield data which reflected a yield response to phosphorus only in the case of corn produced at the Gerald

Steely Farm.

9. High levels of nitrogen and phosphorus were reflected in amount of plant material produced early in the growing season. Grain yields at the Ashland Agronomy Farm and at the Gerald Steely Farm were also related to this factor for reasons previously outlined.

10. It should be noted that the highest levels of N and P were not necessarily associated either with maximum early season growth production or with best grain yields.

11. Cations (Na, K, Ca and Mg) varied significantly in only some cases. Apparently not much importance can be attached to these variations because such did not seem to relate to yields nor to fertilizer composition. Addition of fertilizer was not effective insofar as stimulating the accumulation of any of these cations (Na, K, Ca and Mg).

12. Amounts of nutrients accumulated varied as follows: K $>$ N $>$ P $>$ Ca $>$ Mg $>$ Na.

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NUTRITIONAL STUDIES WITH CORN

by

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Three experimental locations were utilized in this study for purpose of comparing four phosphate containing fertilizers. Phosphate containing fertilizers used in this experiment were: ammonium nitrate-phosphate (30-10-0), ammonium phosphate (11-48-0), triple superphosphate (0-45-0), and ammonium polyphosphate (15-60-0). Ammonium nitrate (33.5-0-0) was used as a supplementary source of nitrogen in the cases of the 11-48-0, 0-45-0 and 15-60-0 treatments. It also provided nitrogen where only that element was involved in the experimental treatment. Rates of nitrogen at the Agronomy Farm and the Gerald Steely Farm corresponded to 80 and 120 pounds per acre. At the Ashland Agronomy Farm, rates of this element corresponded to 120 and 160 pounds per acre, phosphate rates were 27 and 40 pounds of available P_2O_5 at the Agronomy Farm and Steely Farm and 40 and 53 pounds per acre of available P_2O_5 at the Ashland Agronomy Farm.

Methods of applying fertilizer included both broadcasting and banding along the row at time of planting. At the two Manhattan locations (Agronomy Farm and Ashland Agronomy Farm), each phosphate containing material was banded in conjunction with the total nitrogen provided and each, with the exception of the 30-10-0 fertilizer, also was banded independently of its supplementary nitrogen. Ammonium nitrate, when used without phosphate, and 30-10-0 fertilizer were compared as broadcast treatments. At the Steely Farm, all applications of fertilizer were banded.

Treatments were replicated five times in a completely randomized block of plots. Each individual plot consisted of four forty-inch rows of corn extending for a length of 60 feet.

Chemical analyses of the soils were made to evaluate the nutrient supplying power of the growth media. Whole plants, about one month old, were collected from the various treatments at each location. The samples were analyzed for N, P and four metallic cations (K, Na, Ca and Mg). Analyses of variance were made on the data obtained relative to both yield and chemical composition.

The results of the experimental data indicated:

1. Corn did not show yield response for any fertilizer used at Agronomy Farm with the exception of the banded ammonium nitrate and ammonium phosphate combination at the rate of 120 pounds of N and 40 pounds of available P_2O_5 per acre. This same location did not show any significant decreases for fertilizer application.

2. Yield responses, ranging from 80 to 90 bushels per acre, were found with nitrogen alone at the Ashland Agronomy Farm. Corn did not respond to phosphate at this location.

3. Response of corn to nitrogen was not found at the Gerald Steely Farm, but banded phosphate did give a response of 12 to 16 bushels per acre.

4. Interaction between nitrogen and phosphorus generally caused the most early season growth response.

5. High levels of nitrogen and phosphorus were generally reflected in the amount of material produced early in the season and to a certain extent in the final grain yield.

6. The highest levels of N and P were not necessarily associated with either maximum early growth or highest grain yields.

7. Levels of 0.364 and 0.449 percent phosphorus at the early sampling insured an adequacy of this element for the plants needs, but a level of 0.292 was inadequate for later development, as indicated by grain production.

8. Addition of fertilizer was not effective in stimulating cation accumulation (Na, K, Ca, and Mg).

9. Quantities of the various elements in the corn plant varied as follows: $K > N > P > Ca > Mg > Na$.