NUTRITIONAL STUDIES WITH SOYBEANS

by

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INTRODUCTION

Of late, much interest is being devoted to the determination of the exact mineral requirements of field crops. In this country and abroad, excellent research has been done to investigate, ascertain and establish the basic principles of mineral nutrition of plants.

The soybean crop is important as food for man and feed for the beast. Also, it is being pressed into new uses as raw material for scores of industrial products. From the dawn of the nineteenth century, when it was introduced in the United States from the Orient, it has risen from obscurity to a place of major importance in the agriculture of this country. Annual production in this country now approaches 400 million bushels, which is surpassed only by wheat, cotton, tobacco, potatoes and corn. This production constituting roughly one-half of the total world supply is produced on some twenty million acres.

About one-half of this soybean acreage is in the North Central Region, the remainder is in the Mississippi Delta and the Atlantic Coast Region. Kansas raises 95 percent of its seven million bushels in the east end of its five tiers of counties where climate for this crop is well suited.

Acre yields are still low. In order to gain an insight in the nutritional aspect of this plant, this study was begun and conducted. It was hoped that the knowledge gained in the process would give a better insight, such that it could be pressed into service to raise better crops that were rich in food and bumper in yields and at the same time allow the fertility of the soil to be maintained.

REVIEW OF LITERATURE

Excellent correlation between crop yields and the application of proper nutrients to the soil have been shown by Smith et al. (33). At the Columbus Experiment Field, crop yield trends were observed to evaluate cropping systems and the soil treatments. That fertility was an important problem in soybean production was evidenced in the response of the crop to lime; lime and superphosphate; lime and rock phosphate; lime, superphosphate and manure; lime, rock phosphate and manure; and lime, superphosphate and potash; over the years from 1931 to 1954 when yield levels of 112, 124, 132, 137, 133 and 134 per cent respectively were observed in comparison with untreated soil rated as 100 per cent. Although soybeans responded less to the various treatments than most of the other crops studied, evidence was considerable that the increases were significant, and also that potash application resulted in consistent increases in yields.

The studies of Swanson as quoted by Call and Throckmorton (10), and of Bhangoo and Smith (5) and others showed that the Cherokee silt loam, the soil on which the crop for the study was raised, is definitely low in fertility, especially in phosphorus supplying power. As compared to a fertile soil, 2,000 pounds of total nitrogen, 480 pounds of phosphorus, 11,200 pounds of potassium and 6,000 pounds of calcium per acre contained by the Cherokee silt loam are only 1/3, 1/4, 1/4 and 1/2 respectively of the required nutrient supply.

Soybeans have alternately been regarded as a soil improving and ruining crop. The ambiguity of such controversial statements can easily be explained by a consideration of the comparable nutrient additions and losses when the crop is used in different ways. Sears (32) estimated that 88, 26 and 16 pounds of nitrogen were added per acre when the crop was used as green manure, hay with manure returned to the soil, or seed with straw left in the soil. When seed or straw were removed, or the crop without manure being returned to the soil, losses of 3 and 30 pounds respectively of nitrogen per acre occurred.

Sears' estimations were based on a crop of 20 bushels of seed, or 4,500 pounds of hay per acre. Approximately two-thirds of the nitrogen requirements of the plant were assumed to be met from the atmosphere.

Norman and Krampitz (25) found the probable range of nitrogen fixation on average prairie soils to be in the order of 20 to 35 percent of the total used by the plant. Sears' above estimate is probably too high and even if straw is returned, removal of a seed crop may result in nitrogen depletion.

Soybeans were found to have heavy demands on both major and minor nutrient elements. Sears showed that a crop of soybeans removed somewhat more phosphorus and magnesium and about three times more potassium and seven times more calcium than crops of corn, oats or wheat with comparable yields. Norman (25) also reported that the nitrogen required by soybeans was somewhat in excess of what was needed by comparable yields of corn. But, soybeans had the faculty of entering into a symbiotic relationship with a species of rhizobium -- Rhizobium japonicum, (21a) to supplement its supply of nitrogen.

Morgan, as quoted by Jackson (18) reported that 5.0 was the minimum pH for growth of soybeans and the desirable pH range was from 5.2 to 7.0. According to Albrecht, calcium is required by soybeans more than any other element for nodulation, and as such its supply was the principal factor and the pH was important as it related thereto. At low levels of calcium saturation, Albrecht found that the phosphorus in the seed was lost to the substrate and there was no growth and nitrogen fixation in six weeks. When 0.2 m.e. calcium was supplied for each plant, all phosphorus was retained and there was a good growth of the plant with satisfactory nodulation. Lipman and Blair (20), Albrecht and Davis (1), Moser (24), Horner (16), and others have also emphasized the importance of calcium for the nodulation and nitrogen balance of the soybean plants.

A high calcium content was usually accompanied by a low potassium content and vice versa in soybeans. Loehwing (21) reported that additions of calcium may cause starvation of potassium on soils low in the element.

MacTaggart (22) reported that lime and phosphorus together increased the weight and total nitrogen content of soybeans more than lime alone. Helz and Whiting (15) claimed that rock phosphate stimulated nodule production. Wilson (34) found a correlation between liming of soils and the phosphorus content of the soybeans raised on them. Hutching (17) suggested a relatively close relationship between calcium, phosphorus and nitrogen in the soybean production. With adequate calcium, applications of phosphorus resulted in greater concentration of phosphorus in the plant tissues. In the early stages of growth, however, phosphorus was not found to be a significant factor.

Fred et al., (12) reported a nitrogen hunger period in young soybean plants, after cotyledonary nitrogen was exhausted and before the nodules supplied an adequate supply. Either by shading the plants or by addition of combined nitrogen, fixation of nitrogen was initiated.

Allen (3) found a direct relationship between the amount of potassium in the nutrient solution and the percentage of that element in the plant tissue. An inverse relationship with respect to the percentages of calcium and magnesium was observed under the same conditions.

Graham (13) found that an adequate supply of magnesium facilitated the efficient use of the calcium offered. No fixation of nitrogen was observed when magnesium was excluded.

Hamner (14) reported that of the cations, calcium, magnesium and potassium, variations in potassium concentrations resulted in greatest vegetative growth responses. With a high level of potassium good growth of soybeans followed even though calcium and magnesium concentrations were low. With low potassium, the young plants were hit by a severe chlorosis, particularly when calcium and magnesium concentrations were high.

In so far as the response to the potassium fertilization is concerned, Bower and Pierre (8) working on high lime soils claimed that soybeans were intermediate between corn and sorghum (very responsive to potash) on the one hand and sweetclover and buckwheat (not responsive to potash) on the other. Although soybeans drew heavily on calcium, their potassium requirement was also found to be high, resulting in an intermediate calcium-magnesium:potassium ratio.

Jackson (18) summarizing a discussion on the interpretation of plant tissue analyses, stated that the concentration of a certain nutrient element varied according to the activity of that element in the soil, the age and part of the plant studied, its yield and the climate under which it was grown. With sufficient balanced activity of the respective nutrients in the growth medium, a satisfactory intensity of nutrition for the plant was secured. Tables 1 and 2 give a comparative study of the concentration of major and minor nutrient elements as given by Jackson for the soybean and other leguminous seeds.

Table 1. Concentration of major nutrient elements in some legumes as compared to soybeans.

Legume	Percentages				
	P	K	Ca	Mg	S
Alfalfa	0.1-0.5	0.5-4.5	0.5-4.5	0.2-0.4	0.2
Clover, red	0.2-0.3	1.1-3.4	1.1-2.1	0.4-0.7	0.2
Soybean seed	0.5-1.1	0.8-2.4	0.2-0.3	0.2-0.3	0.1-0.2

A more detailed treatment was given by Miller (23) which was developed from studies of original analyses of the nutrient content of various feeding stuffs. The data, some of it unpublished till then was furnished by the United States Department of Agriculture, State Agricultural Experimental Stations and the private industry.

Table 2. Concentration of trace elements in some legumes as compared to soybean seeds.

Legume	Parts per million				
	Fe	Mn	Cu	Zn	B
Alfalfa	130-1000	10-120	4-15	14-110	4-30
Clover, red	100-1300	25-540	6-20	24-70	36
Soybean seed	60-570	20-280	4-12	27-80	2-29

In Table 3, compiled from Miller (23), some pertinent information bearing on the subject regarding the composition of soybeans is presented.

MATERIALS AND METHODS

Chemical Analysis of the Soil

Soil material on which this crop was raised was analyzed in the laboratory using the standard procedures of chemical analysis. The analyses included the determinations of pH, lime requirement, total nitrogen, available phosphorus, cation exchange capacity, exchangeable cations, organic matter, water-soluble cations, the electrical conductivity and the pH measurements of the soil saturation paste.

The pH values of the different soil samples were measured by use of the glass electrode system of a Beckman pH meter. To five grams of soil taken in a 1 1/4 oz. wax paper cup 5 ml. of distilled water was added (18). The mixture was allowed to stand for at least 20 minutes keeping it stirred at intervals and just before taking the final readings. Lime requirements for any particular sample was determined by the use of Woodruff's buffer solution (35). To samples having pH values of 6.2 or less, 10 ml. each of the buffer solution was added to the soil mixtures, stirred, allowed to stand for at least 30 minutes, stirred again and read again on the pH meter. For every tenth of a pH unit under pH 7.0 one thousand pounds of lime were recommended.

Total nitrogen in the soil samples was determined by the Winkler's boric acid modification of the Kjeldahl method as reported by Jackson (18). Ten gram samples of 100-mesh soil were digested by 30 ml. portions of concentrated sulfuric acid. A mixture made up of 10 parts

Table 3. Mineral composition of soybeans.

Plant fraction	Dry Matter per cent		Calcium per cent		Phosphorus per cent		Potassium per cent		Magnesium per cent	
	Mean Min.	No. Max.	Mean Min.	No. Max.	Mean Min.	No. Max.	Mean Min.	No. Max.	Mean Min.	No. Max.
Soybean Forage	23.0	23.1	1.30	45	0.53	74	1.06	22	0.59	24
all analysis	16.2	29.0	1.01	1.84	0.19	1.78	0.71	2.31	0.36	0.88
Soybean leaves	----	----	2.09	80	0.26	100	0.72	100	1.12	100
			1.64	2.40	0.12	0.41	0.48	1.01	0.80	1.41
Soybean pods	----	----	0.99	40	0.20	40	0.93	40	0.82	40
			0.85	1.12	0.11	0.33	0.79	1.07	0.70	0.93
Soybean stems	----	----	0.83	100	0.25	100	0.51	100	0.81	100
			0.62	1.01	0.15	0.35	0.26	0.90	0.81	100
Soybean forage	19.7	24	1.71	11	0.30	11	1.19	6	0.72	6
milk stage	16.2	23.9	1.47	1.79	0.24	0.39	0.96	2.31	0.67	0.77
Soybean forage	25.7	47	1.31	8	0.31	8	0.79	4	0.83	4
dough stage	20.6	29.0	1.23	1.44	0.21	0.40	0.71	0.88	0.78	0.88

K_2SO_4, 1 part $FeSO_4$ and 0.5 parts $CuSO_4$ was used as a digestion accelerator. To the digest 110 ml. of 12 N NaOH solution was added and distilled. Distillate was collected in 4 percent boric acid solution. This later was back titrated with N/14 H_2SO_4. The results were reported in percent of nitrogen in the sample.

Available phosphorus was determined by a modification of Bray's sulfonic acid reduction colorimetric method. Five grams of air dried 10-mesh soil was extracted with 50 ml. of extracting solution which was 0.025 N with respect to HCl and 0.03 N with respect to NH_4F. A Coleman Junior Spectrophotometer was used to determine the amount of phosphorus in the filtrate.

For the cation exchange capacity measurements, the methods as outlined by Jackson (18) and Rogers (29a) using the centrifuge technique and a Beckman model DU flame photometer with a No. 4300 photomultiplier attachment was employed. Two grams of 10-mesh soil was used. The exchange complex of the soil was saturated, in the first instance, with calcium, the excess salts were later leached by alcohol in the second step, and thirdly, the adsorbed calcium was extracted.

Exchangeable metallic cation species of the soil samples were also determined by the use of the centrifuge technique and flame emission methods outlined by Jackson (18). Standard solutions used to calibrate the flame photometer contained approximately the same ratio of cations as the unknown solutions so that the errors due to the interferences of cations could be minimized (4, 7, 29a and 31).

Organic matter was determined by the Walkley-Black method as given by Jackson (18). Diphenylamine was used as the indicator.

The soils were extracted for water-soluble cations, electrical conductivity and pH measurements. A saturation paste was prepared according to the method detailed by the United States Salinity Laboratory Staff (30). To determine the pH of the saturated soil paste, a pH meter with a glass electrode assembly was used. The saturation paste was allowed to stand in the Buchner funnels for 4 to 16 hours (30) so that the soluble gypsum might achieve equilibrium. Then suction was applied with a vacuum pump to remove the saturation extract.

The electrical conductivity of the saturated extract was measured on an Industrial Instruments, model RC-BC, conductivity bridge with a pipette type conductivity cell.

The water-soluble cations were determined on the Beckman DU flame photometer by reference to the standard curves for the respective cations.

Experimental Design

For this study, the crop as grown in southeastern Kansas at the Columbus Experiment Field located in Cherokee County was used. The soil of the area, named Cherokee silt loam, has, more often than not, an ashy gray surface soil and a very impervious clay pan underneath. One of the most acidic soils known, in the state, Cherokee silt loam is level in topography, where water stands during rains. Due to this, good stands of crops like alfalfa, soybeans and sweetclover cannot be secured without lime.

Table 4 lists the treatments given to the fertility plots that were used for this study.

The rotation practiced on these fertility plots in recent years was as follows:

Alfalfa, alfalfa, corn, soybeans, wheat, wheat.

Collection and Preparation of Plants for Analysis

Whole plants for this study were taken from the variety S-100, sown on the fertility plots. This late variety is best suited to southeastern Kansas and is known to have a high protein content, resistance to lodging, and erect plants. It was seeded on May 29 and harvested on October 22, 1958. Representative plants, taken at random, were gathered at different stages of growth as follows:

1. First sampling -- four weeks after seeding.
2. Second sampling -- eight weeks after sampling.
3. Third sampling -- pod filling stage.

Table 4. Treatments for soybean fertility plots at Columbus Experiment Field.

No.	Treatment	Description
1.	Lime*	
2.	Lime + S.P.	20 lbs. of available P_2O_5 from S.P. applied at the time of planting.
3.	Lime + S.P. + K_2O	20 lbs. of P_2O_5 as in No. 2 + 20 lbs. of K_2O drilled before planting.
4.	Lime + S.P. + MgO	P_2O_5 as in No. 2 + 100 lbs. of $MgSO_4 \cdot 7H_2O$ at planting time.
5.	Lime + S.P. + Manure	P_2O_5 as in No. 2 + 8 tons of barnyard manure before plowing for soybeans.
6.	Lime + R.P.[1] + Manure	Manure as in No. 5 + R.P. at the rate of 1,000 lbs. per acre before seeding alfalfa and 333 lbs. before wheat and after soybeans.
7.	Lime + S.P.	Same as in No. 2.
8.	Control	No lime, no fertilizer.

*Lime to the fertility plots was applied in this wise: 1927 = 3 tons per acre; 1941 = 1½ tons per acre; 1953 = 3 tons per acre; total = 7.5 tons per acre.

[1]This treatment was included in this study at the time of second sampling.

The plants for chemical analysis from each collection were divided into three portions viz., roots, stems and leaves, excepting the third sampling, when a new separate, the pods, was added, thus making a total of four separations at the final sampling.

After sampling, the various plant fractions were dried in a forced-draft oven at 70° C. for three to five days. Later, these fractions were finely ground in a Wiley mill, mixed well and stored in tightly stoppered bottles.

Chemical Analysis of Plant Material

The various plant fractions were analyzed for nitrogen content, phosphorus and the metallic cation species. The methods used were as follows:

Nitrogen: The Kjeldahl-Gunning method (27) with slight modifications was used usually on one gram samples of the ground plant material.

Phosphorus: To determine the amount of phosphorus in the organic material, a colorimetric procedure (27) was used. Five ml. of alcohol solution containing one gram of $Mg(NO_3)_2 \cdot 6H_2O$ per 2.5 ml. ethyl alcohol were added to 0.4 grams of ground plant material and ignited to high temperatures of 550° C. The residue was taken up in 10 ml. of 2 N HCl, filtered into a 100 ml. volumetric flask and adjusted to the end point with 0.2 N NaOH using a few drops of phenolphthalein as indicator. After making to volume two ml. each of ammonium molybdate-HCl-H_3BO_3 solution (P-B) and reducing solution (P-C) of amino-naphthol-sulfonic acid were added, and allowed to stand for fifteen minutes. The transmittancy of this solution was determined in a Coleman Junior Spectrophotometer using a wavelength setting of 660 millimicrons. The galvanometer readings were applied to a standard graph prepared for the determination and the results were calculated in parts per million of phosphorus in the plant material.

<u>Cations</u>: In order to make the determination for the cations, calcium, potassium, magnesium, and sodium, the plant material was digested by the wet digestion method. This procedure is essentially that as described by Early (11), involving a dilute mixture of water, perchloric and nitric acids. One gram to two gram samples of the finely ground material were used and a Beckman flame photometer with a photo-multiplier was employed. The standard solutions used to calibrate the flame photometer had the same ratio of cations as the unknown solutions in order to minimize the cation interferences (4, 7, 31). Also, the acids known to be present in the unknown solutions were added in equivalent amounts to the standard solutions.

EXPERIMENTAL RESULTS

Yield Data

Yield data for the Columbus Experimental Field soybean plots for the year 1958 are represented in Table 5. As may be observed, there was a marked response to certain fertility treatments. An increase of about 14 bushels per acre over the control plot was obtained for the best treatment which included lime, superphosphate and manure. This increase of fourteen bushels per acre was distributed approximately as follows: about two bushels for lime, three bushels for superphosphates, at least four bushels for the potash contained in the manure, and an additional quota of five bushels for other benefits supplied by the manure. These latter effects may have been due to nitrogen and magnesium furnished by the manure. Sulfur may have been a factor, too.

Table 5. Soybean yield data, Columbus, Kansas, 1958.

No.	Treatment	Bu./A.
1.	Lime	27.1
2.	Lime + S.P.	30.2
3.	Lime + S.P. + K_2O	34.5
4.	Lime + S.P. + MgO	32.6
5.	Lime + S.P. + Manure	39.1
6.	Lime + R.P. + Manure	35.9
7.	Lime + S.P.	30.2
8.	Control	25.2

The year 1958 was unique in the sense that it promoted the best growth of the crop at Columbus since 1931, by providing good moisture and favorable conditions. This was reflected in marked response of the plants to various fertility treatments. Even the control plot of 1958 yielded more than the best treatment of 1947, another year of excellent yields and large responses to fertilizers.

Analyses of Plant Materials

The data from the soybean plant analyses are presented in Tables 6-8, inclusive. Each fraction, the leaves, stems, roots and the pods have been classified separately for ease in comparison.

The tables represent definite stages in the life of the soybean plant. Table 6 gives the data in the early stage of growth, Table 7 reflects the nutrient status of the plant in a rapid growth period, and Table 8 portrays the stage when the plants were engaged in the process of seed production.

Table 6. Chemical Analysis of Soybeans, June 20, 1958.

Treatment	Cations Milliequivalents/100g. K	Na	Ca	Mg	Total	Per cent nitrogen	P. (ppm)
			Leaves				
Lime	36.9	0.9	86.7	75.5	200.0	5.55	2,250
Lime + S.P.	30.0	1.1	80.5	83.3	194.9	5.47	3,062
Lime + S.P. + K_2O	42.1	1.2	78.1	83.3	204.7	5.65	3,000
Lime + S.P. + MgO	35.3	0.9	86.7	104.2	204.7	5.35	3,200
Lime + S.P. + Manure	46.1	0.8	78.9	62.5	188.3	5.62	3,062
Lime + R.P. + Manure	----	----	----	-----	-----	----	-----
Lime + S.P.	32.4	1.1	80.5	100.2	214.2	5.36	3,250
Control	37.3	0.8	81.2	83.3	202.6	5.23	1,875
			Stems				
Lime	46.2	2.9	90.6	78.1	217.8	3.47	1,656
Lime + S.P.	34.0	3.0	89.4	80.2	206.6	3.55	2,275
Lime + S.P. + K_2O	66.0	2.8	100.0	107.3	276.1	3.49	2,275
Lime + S.P. + MgO	39.1	2.9	87.5	107.3	236.8	3.55	2,650
Lime + S.P. + Manure	76.1	2.5	88.1	68.8	235.4	3.58	2,500
Lime + R.P. + Manure	----	----	-----	-----	-----	----	-----
Lime + S.P.	36.2	3.3	81.2	80.2	200.9	3.71	2,712
Control	47.1	2.7	84.8	80.2	214.8	3.35	725
			Roots				
Lime	27.4	10.1	30.3	39.8	107.6	2.03	1,725
Lime + S.P.	22.0	13.0	30.6	38.0	103.6	2.07	-----
Lime + S.P. + K_2O	38.7	9.3	30.2	31.2	109.4	2.08	1,217
Lime + S.P. + MgO	24.4	11.4	30.2	43.5	109.5	2.05	750
Lime + S.P. + Manure	43.1	9.5	29.7	40.0	122.3	2.08	1,650
Lime + R.P. + Manure	----	----	-----	-----	-----	----	-----
Lime + S.P.	20.2	13.6	24.2	40.2	98.2	2.08	1,350
Control	31.9	9.3	27.1	35.5	103.8	1.95	500

First Sampling, June 20, 1958

Leaves: Table 6 shows that concentration of calcium and magnesium were greater in magnitude than either potassium or sodium in the soybean leaves. The accumulation of calcium was relatively constant and at a high level. Magnesium accumulation apparently was increased when that element was included as part of the soil treatments that included either muriate of potash or manure. This increase in the potassium content in the leaf tissue was accompanied by a corresponding increase in the nitrogen content over the other treatments that did not receive the increased dose of potassium. Although total cation accumulation was not an absolute constant, there seemed to be some tendency for this to be the case. Three weeks after planting about 200 m.e. of cations per 100 grams of plant material were found to prevail. Sodium accumulation was low in all treatments.

Nitrogen accumulation did not show great variations, but level of nitrogen in the plants from the control plants was lower than in the plants grown on plots that included a lime treatment. That there was some correlation between the potassium content and the amount of nitrogen in the leaf tissue was suggested in the data by an increase in the percentage of nitrogen in the plants receiving potassium in the treatment.

Phosphorus content of soybean tissue from the control plot was found to be low. An increase in the phosphorus status was evidenced in the plant material from the limed plot, the analysis showed an increase of 375 ppm over the control plot even though phosphorus was not included in the treatment. With the inclusion of phosphorus a considerable increase of that element in the plant was secured.

<u>Stems</u>: As in the leaves, the concentration of calcium was high and was matched only by the magnesium content. For the most part, the calcium content tended to be at a constant level. The magnitude of magnesium content was the highest in the plant material from the plot that received magnesium treatment and the lowest in the plant material from the manured plots. Addition of lime and superphosphate did not seem to reflect any increase in the level of magnesium over the control. A marked increase in potassium accumulation was noted in the composition of plants receiving potash or manure. Plants that received only lime and superphosphate had only about one-half as much potassium as those that were grown on plots incorporating K_2O or manure in the treatment. There was a relatively low level of potassium in plant material produced when superphosphate and magnesium sulfate comprised the treatment in addition to lime. The uptake of sodium was still low but not so low as in the case of leaves.

The total cation accumulation showed much greater variation in the stems than in the corresponding leaves.

The percentage of nitrogen in the plants from the control plot was lower than the other plants grown on plots receiving lime and other nutrients. A lower overall quantity of nitrogen was noted in the stems than in the leaves.

On the control plot the phosphorus was markedly low. Analysis showed that the phosphorus content of the stems from the limed plots was more than double than that in the control plot and the other treatments caused an increase of three to four times in the uptake of phosphorus by the soybeans as compared to the control.

Roots: Much lower total cation accumulation was observed in the case of roots. Again, the most abundant cations were magnesium and calcium, magnesium showing a little edge over the calcium content. The correlation between the application of magnesium to the soil and that reflected in the tissue material was not so marked as in leaves and stems, though it was still very obvious.

More sodium was present in roots than in either the stems or leaves. Lime and superphosphate treatment seemed to result in higher uptake of sodium than did the rest of the treatments.

Accumulation of potassium was less by roots than by above-ground parts of the plant. There was a definite evidence of the uptake of potassium and accumulation of that element in the plant tissue when the concentration of the nutrient was increased in the medium. An admittedly small but still definite upward trend was noticeable in the amount of nitrogen accumulated by the plants when either muriate of potash or manure was included in the soil treatment. The additions of lime seemed to raise the level of nitrogen in the plant material.

In the case of phosphorus concentration in the soybean roots, the inability of the plants seeded in the control plot to absorb phosphorus was most significant when compared to the plants from plants that received either manure or potash in the soil treatment. The application of lime alone seemed to effect a three-fold increase over the control. Unfortunately, the results from one of the treatments, lime and superphosphate, could not be reported as no material was available for making the determination. However, the results from the other lime and superphosphate treatment serve to indicate that the incorporation of

P_2O_5 in the soil gave a significant increase in the amount of phosphorus accumulated by the plants.

It was noted that total amount of nitrogen and phosphorus was distributed in the plant in such a way that the concentrations of these nutrients were greatest in the upper portions of the soybean plant and there was a decrease in amount at the base of the plant.

Second Sampling, July 23, 1958

Leaves: Analytical data showed that the most abundant cation in the soybean leaves at the time of most active growth was magnesium whose concentration was somewhat higher than calcium and considerably greater than the accumulation of potassium (Table 7). The plants growing on soil receiving the magnesium treatment had 134.1 me. found in the plants on the control plot. The application of muriate of potash seemed to have a depressing effect on the uptake of magnesium. The potassium present in the manure also seemed to have a probable depressing effect on the magnesium uptake. This latter effect was more evident in the case where superphosphate was used than where rock phosphate was involved. An inverse relationship between the amount of calcium and magnesium was observed, especially in the absence of applied potash.

The concentration of calcium in the soybean leaves tended to be constant except in the treatments that received either magnesium or potash, where a slight depressing effect of the latter nutrients on calcium was noticeable. (The concentration of calcium was quite high).

In the period of quick growth of soybeans the shortage of potassium in the tissues produced on plots which were not treated was quite noticeable. The application of potash showed an increase of 25.6 m.e. of

Table 7. Chemical Analysis of Soybeans, July 23, 1958.

Treatment	K	Na	Ca	Mg	Total	Nitrogen (%)	P. (ppm)
	Cation Milliequivalents/100g.						
Leaves							
Lime	67.3	1.5	93.0	118.5	280.3	4.09	2,950
Lime + S.P.	58.5	.8	93.0	134.1	286.4	4.24	3,188
Lime + S.P. + K_2O	82.5	.7	86.0	85.9	255.1	4.25	2,662
Lime + S.P. + MgO	56.9	1.2	87.1	134.1	279.3	3.76	2,750
Lime + S.P. + Manure	76.9	.9	91.4	97.6	266.8	4.19	3,112
Lime + R.P. + Manure	78.1	.8	93.0	117.2	289.1	4.34	3,188
Lime + S.P.	64.1	.7	93.8	134.1	292.7	4.24	3,188
Control	56.9	.7	93.0	100.3	250.9	3.83	1,912
Stems							
Lime	43.1	.4	49.7	78.1	171.3	1.87	1,562
Lime + S.P.	33.6	.6	44.4	83.3	161.9	1.94	1,812
Lime + S.P. + K_2O	57.7	.4	50.1	72.9	181.1	1.73	1,675
Lime + S.P. + MgO	34.7	.4	47.0	80.2	162.3	1.78	1,750
Lime + S.P. + Manure	53.5	.4	46.4	76.0	176.3	1.85	1,850
Lime + R.P. + Manure	52.9	.5	48.0	59.4	160.8	1.85	1,812
Lime + S.P.	32.2	.6	43.6	83.3	159.7	1.73	1,625
Control	41.7	.5	42.5	56.2	140.9	1.50	1,012
Roots							
Lime	20.2	4.5	18.2	29.7	72.6	0.79	462
Lime + S.P.	17.0	9.6	21.6	24.0	72.2	1.08	800
Lime + S.P. + K_2O	32.8	4.7	18.8	21.5	77.8	0.91	675
Lime + S.P. + MgO	16.0	5.4	16.8	30.0	68.2	1.02	1,062
Lime + S.P. + Manure	33.4	4.2	16.6	24.5	78.7	0.94	1,062
Lime + R.P. + Manure	31.8	3.8	19.9	19.8	75.3	0.98	1,050
Lime + S.P.	15.0	8.3	20.6	24.0	67.9	1.04	832
Control	14.62	2.8	16.8	16.5	50.7	0.76	378

potassium in that treatment over control which had only 56.9 m.e. This difference in potassium accumulation probably influenced the yield response of these different treatments.

The sodium content was still low in the soybean leaves.

It was observed that potassium and magnesium were now more abundant than at the first sampling. With some treatments there was from 30 to about 50 percent increase over the amount encountered at the time of first sampling. This effect contributed to an appreciably greater accumulation of total cation uptake.

Nitrogen accumulation by the plants on the control plot was significantly lower than in the plants from the plots that received lime and other nutrients. Addition of lime added 0.26 percent nitrogen over the control plot and an increase of 0.51 percent nitrogen was observed with the application of lime, superphosphate and manure. That lime, phosphates, potash or magnesium increased the nitrogen content was evident and was reflected by the analyses.

Phosphorus status of the plants produced on the control plot was faulty too. Incorporation of P_2O_5 in the treatment invariably had the effect of increasing the accumulation of phosphorus by the plants. Apparently such increases contributed to increased yields.

Stems: The accumulation of calcium in the soybean stems was roughly one-half of that in the leaves at the second sampling. Application of lime to the soil effected some increase in the uptake of calcium by the plants.

As in the case of leaves, the most abundant cation in the soybean stems was magnesium. The correlation of magnesium in the medium with that found in the tissue material was evidenced by the plot receiving an addition of $MgSO_4 \cdot 7H_2O$ which showed an increase of 24 m.e. of magnesium over the 56 m.e. level of the control plants. The inverse relationship between the nutrients calcium and magnesium was also observed in several instances; an increase in the calcium status was reflected in a depression of the magnesium level in the stems and vice versa.

It was interesting to note that while there was an increase in the level of potassium, magnesium and calcium in the leaves of the second sampling as compared to the leaves of the first sampling, the stems did not show any such corresponding increase. In fact, the concentration of these cations showed a down-ward trend, probably this could be attributed to a translocation of the nutrients to the leaves for the performance of essential processes for the growth and development of the plants.

The effect of potash and manure on the potassium content of stems was very marked. As compared with 41.7 m.e. of potassium per 100 grams of tissue from the control plot, the analysis of plants from plots receiving the treatments lime, superphosphate and potash; lime, superphosphate and manure; and lime, rock phosphate and manure revealed potassium concentrations in the order of 57.7, 53.5 and 52.9 m.e. respectively. It seemed that increased uptake of potassium did much to increase the yields of soybeans.

The concentration of sodium was still observed to be quite low, at a fairly constant and uniform rate.

Total cation accumulation in stems was decidedly at a lower level than was true at the first sampling. This decline was accounted for mainly by a loss of calcium. One pattern was more clear now than at the first sampling, total cation accumulation was more uniform now.

The magnitude of nitrogen accumulation by the soybean stems in the second sampling was much less either from the leaves of the same sampling or from the stems of the first sampling. Probably this was due to the fact that the plants being engaged in quick growth, the bulk of the nitrogen supply was translocated to the leaves to enter into the structure of the chlorophyll, protoplasm and the initiation of meristematic activity. The nitrogen accumulation by the plants on the control plot was poor in comparison to the plants grown on limed and fertilized plots. The greatest response was shown by the treatment lime and superphosphate followed by the plants from plots that were given lime, rock phosphate, manure; or lime, superphosphate and manure. Increased nitrogen accumulation seemed to have a pronounced effect in causing higher yields of soybeans.

Phosphorus uptake again was about one-half that in the leaf samples of the second sampling, but unlike the nitrogen content of the stems, there was not observed to be any decline in the rate of phosphorus accumulation in the second sampling from what was observed in stems in the first sampling. The same poor pattern of phosphorus uptake was noticeable in the tissue material from the control plot as seen earlier. A much vigorous and healthy accumulation was noted in the plants that grew on the plots which received supplemental phosphorus. The plants on manured plots and on plots that received only lime and 20 pounds of P_2O_5 reflected increases in the phosphorus accumulation in the tissue that were more than about 80 percent in magnitude.

Roots: Data in Table 7 showed that the nutrient accumulation by the roots was quite low in comparison to either stems or leaves from the second sampling or from the roots in the first sampling. Magnesium was still the most abundant cation, it still reflected the fact that the application of magnesium to the substrate increased the activity of that element in the plant tissue, the inverse relationship between calcium and magnesium as well as magnesium and potassium were suggested, but the analyses seemed to suggest that the translocation of the nutrient ions at this stage of growth was most rapid to the above-ground parts of the plant.

The addition of lime to the soil medium generally increased the calcium status of the plants, except where it was accompanied by addition of superphosphate and $MgSO_4 \cdot 7H_2O$ or by addition of superphosphate and manure. Presence of magnesium or potassium in the treatment seemed to counteract the effects of calcium supplied by lime.

The potassium accumulation by the soybeans was more than doubled over the plants from the control plot if muriate of potash was included in the treatment. Manure showed the same trend and the response was even a little greater in the treatment lime, superphosphate and manure. Manure, rock phosphate and lime gave similar results. Application of lime alone increased the uptake by about 150 per cent when compared to the control plots. The inclusion of magnesium in the treatment apparently had a depressing effect on the potassium uptake, although the level of potassium uptake was still a little higher than in the material from the control plot.

Although there was a many fold increase in the amount of sodium accumulation by the soybean roots in the second sampling, it was low. Lime and superphosphate treatment gave the biggest increase followed by that which involved $MgSO_4 \cdot 7H_2O$.

The total cation content, though low, was quite uniform.

The level of nitrogen in the soybean roots was low. The least amount was noted in the plants from the control plot and greatest percentage was encountered from the plot that had lime and superphosphate. Possibly the application of lime stimulated the activities of rhizobia, and the presence of phosphates joined in to contribute its beneficial effects on the nitrogen fixation by the soil microorganisms.

The greatest concentration of phosphorus was found in the plants growing on the plots that received lime, superphosphate and manure; and lime, magnesium and superphosphate. The magnitude of phosphate in both the treatments was 1,062 ppm. This was about three times as great as in the control plot which had only 378 ppm of phosphorus. The treatment receiving rock phosphate with lime and manure produced plant material with 1,050 ppm of phosphorus in the tissue.

Third Sampling, September 10, 1958

Leaves: The most noticeable trend with the third sampling was that it was the calcium and not the magnesium ion that dominated any other cation in the leaves of the soybean plants. Although, there was little difference in the accumulation of these two cations, in the plants a build-up from the control treatment was observed for the element calcium which nearly doubled in amount in the case of those treatments which reflected the greatest increases. None of the treatments that received lime as the soil amendment had less than 143.2 m.e. of calcium per 100 grams of plant tissue, whereas, the plants from the control plots had only 84 m.e. per 100 grams of plant material.

The only treatment that caused plants to accumulate magnesium to the same extent as was true for calcium was where lime, superphosphate and magnesium; or lime, superphosphate and manure were applied to the soil. Apparently there was sufficient magnesium in the plant leaves produced on the plot which received lime alone.

Level of potassium in plant tissue was lesser too in the soybean leaves in this stage. Potassium accumulation was especially low in the plants of the control plots. There was a noticeable increase of potassium in the plants from the plots that were fertilized.

The percentage of nitrogen in the leaves was also lower than the leaves analyzed in the earlier stages of growth. Generally, nitrogen accumulation by variously treated plants was found to be rather uniform. However, the plants from plots receiving manure as part of the treatment had a higher nitrogen content. This probably had a significant role to play in giving better yield responses from these plots, over the others.

It was noted that with the maturity of the plant, the amount of leaf phosphorus declined. At the pod filling stage, the least accumulation of the element was observed. The least concentration was observed in the control plot and the greatest amount was noted where potash was included as part of the soil treatment.

Pods: Magnesium was the dominant cation. However, instead of the control plot being at the bottom, the plants from the plot that received only lime, had the least amount of magnesium in this tissue. The greatest concentration was found in plants from the plot that received magnesium as part of the treatment. The treatment lime, rock phosphate and manure gave plants that were very high in magnesium.

Table 8. Chemical Analysis of Soybeans, September 10, 1958.

Treatment	Cations (me/100g.) K	Na	Ca	Mg	Total	Percent nitrogen (%)	P. (ppm)
				Leaves			
Lime	12.8	2.9	157.2	109.4	282.3	2.93	1,750
Lime + S.P.	15.1	3.0	143.8	59.9	221.8	2.64	2,000
Lime + S.P. + K_2O	30.4	2.6	156.6	52.1	241.7	2.51	2,238
Lime + S.P. + MgO	13.3	3.3	159.4	140.6	316.6	2.49	2,100
Lime + S.P. + Manure	19.2	2.7	147.2	151.0	320.1	3.03	2,000
Lime + R.P. + Manure	18.4	2.8	160.9	59.9	242.0	3.17	1,988
Lime + S.P.	13.8	3.4	143.2	51.6	212.0	2.87	2,088
Control	9.3	2.5	84.4	80.7	176.9	2.85	1,488
				Pods			
Lime	39.6	0.8	20.0	38.0	98.4	4.69	3,375
Lime + S.P.	31.5	0.7	25.0	60.9	118.1	4.48	3,600
Lime + S.P. + K_2O	47.0	0.5	46.2	59.9	153.6	4.21	3,500
Lime + S.P. + MgO	34.9	1.0	27.6	97.4	160.9	4.19	3,650
Lime + S.P. + Manure	34.5	0.8	31.2	57.3	124.8	4.83	3,188
Lime + R.P. + Manure	40.1	0.8	29.7	97.4	168.0	4.94	3,225
Lime + S.P.	32.6	1.3	29.7	65.1	128.7	4.45	3,600
Control	37.9	1.4	59.2	44.3	142.8	3.41	2,225
				Stems			
Lime	7.9	0.8	40.6	75.5	124.0	0.69	538
Lime + S.P.	6.5	0.7	36.8	46.9	90.9	0.65	900
Lime + S.P. + K_2O	16.4	1.0	46.9	59.9	123.8	0.65	725
Lime + S.P. + MgO	6.9	1.2	39.1	93.8	141.0	0.67	863
Lime + S.P. + Manure	10.4	1.3	35.0	65.1	111.8	0.75	900
Lime + R.P. + Manure	9.6	1.6	40.0	46.4	97.6	0.89	925
Lime + S.P.	6.3	1.0	38.1	46.9	92.3	0.76	925
Control	10.3	1.1	53.4	69.8	134.6	0.64	500

Table 8. (Cont'd)

Treatment	Cations (me/100g.) K	Na	Ca	Mg	Total	Percent nitrogen (%)	P. (ppm)
				Roots			
Lime	3.9	2.5	10.3	77.6	94.3	0.54	500
Lime + S.P.	5.3	3.6	12.6	57.3	78.8	0.75	988
Lime + S.P. + K_2O	9.3	2.0	9.4	41.7	62.4	0.51	872
Lime + S.P. + MgO	4.8	3.2	12.6	59.9	80.5	0.66	813
Lime + S.P. + Manure	9.0	1.8	14.4	59.9	85.1	0.61	788
Lime + R.P. + Manure	7.1	3.9	20.4	46.4	77.8	0.64	962
Lime + S.P.	5.2	2.8	12.8	59.9	80.7	0.73	850
Control	6.0	2.0	12.3	21.9	42.2	0.59	325

The level of potassium in the pods was at least 15 percent higher than that of calcium in most instances. The treatment of lime, superphosphate and potash had the greatest concentration and lime and superphosphate application yielded the least amount and the margin between the two was considerable.

The treatment of lime alone had the least amount of calcium and it was interesting to note that the control plot had the highest concentration and barring the plants from the potash treatment, the amount of calcium in the plants from the control plot had about twice as much calcium.

Sodium content was generally low. The control plot had the most.

Some variation was observed in the total cation content. The analysis seemed to indicate that the plants in the control plot were making an all-out effort to translocate the cations from the other parts for seed development and this probably was the cause of high concentrations of potassium and calcium. But the levels of phosphorus and nitrogen remained low in the plants which seemed to have been the factor for the lower yield responses observed in the plants. The application of manure was noted to be useful with respect to ahigher accumulation of nitrogen in the tissue. Greater phosphorus accumulation was achieved with the addition of phosphate to the soil. The phosphorus level of tissue from the control plot was significantly lower than from those that had received superphosphate or rock phosphate.

Stems: Magnesium was found to be the most abundant cation in the soybean stems in the pod filling stage. The same correlation between the magnesium application and the corresponding uptake of the cation was observed as in the other parts. Plants from the control plot were noted to have fairly highly concentration. However, the plants on the plots receiving lime and superphosphate had the least concentration.

Calcium concentration in the plants from various treatments was found to be fairly high. There was some variation. It was higher in the tissue from in the control plots than in the others.

Potassium content was low in the stems except in plants that received potash or manure as part of the treatment. The lowest levels of potassium accumulation were observed on plots that received lime and superphosphate.

Sodium content was low.

Total cation concentration did not show great constancy. A higher cation content was observed on the control plot. But the nitrogen content of the plants from the control plot was at the lowest level. On the whole, on all plots a very low nitrogen content was observed.

Phosphorus content was least on the control plot and the plot that received only lime also had a low uptake. The application of phosphorus to the other plots and also an application of manure raised the level of phosphorus in the plants.

Generally speaking there was a decline in the amounts of nitrogen, phosphorus and total cations in the third sampling as compared to the first two samplings.

Roots: The analysis showed that roots were high in Mg content but quite low in calcium and potassium. Sodium was relatively more abundant here than was so with other tissues.

Total cation content was also quite low and so were the contents of nitrogen and phosphorus. The control plot plants were found to be low in magnesium, total cation content, nitrogen and especially in phosphorus.

Chemical Analysis of Soils

In order to evaluate the fertility status of the soil from the various fertility plots on which the crop was grown, chemical analyses were made and the results of the determinations are summarized in Table 9.

It was observed that these soil samples represented in themselves to be one of the most acidic soils in the state. The pH value of 5.7 as determined on the soil in the control plot clearly indicated the need for lime if crops like soybeans are to be grown profitably. The soil analysis of the control plot indicated inter alia that pH of the unlimed soil was much lower than that of limed plots and must be regarded as being too low for optimum growth of soybeans.

The organic matter content of each plot was low. However, the application of lime and fertilizer seemed to affect an increase in the organic matter status of the soil.

Total nitrogen content of each plot was low. It was especially low on the control plot. The acidic nature of the soil limited the legume growth resulting in an ultimate lesser nitrogen content of the soil. This lesser content might be due in part to greater losses of nitrogen and in part due to less fixation of nitrogen by rhizobia and by non-symbiotic bacteria.

Available phosphorus was found to have been reduced to a low level on plots receiving only a dose of lime. Additions of phosphates in the form of superphosphate, rock phosphate and manure appeared to have kept the available content of phosphorus at a level that was about twice as high as that on the plot receiving only lime. The control plot had 32 pounds

Table 9. Chemical properties of soil from Experimental Plot, Columbus Experimental Field, Columbus, Kansas.

Treatment	pH	Organic matter (%)	Total nitrogen (%)	Available phosphorus (lbs./acre)	Exchangeable Cations (me 100g.) Ca	Mg	K	Na	C.E.C. me (100g.)	Water-soluble cations Ca	Mg	K	Na	pH of Sat. extract	E.C. of Sat. Extract E.C. x 10^3m mhos/cm, at 25°C.
Lime	6.7	1.9	1.31	12.8	11.25	2.60	0.16	0.26	16.88	0.31	0.10	.01	0.05	6.6	0.40
Lime + S.P.	7.1	1.3	1.33	25.8	11.25	2.81	0.17	0.26	16.88	0.17	0.02	.01	0.02	6.5	0.46
Lime + S.P. + K_2O	7.3	1.7	1.25	22.4	9.77	2.71	0.26	0.20	13.75	0.15	0.07	.02	0.05	6.6	0.39
Lime + S.P. + MgO	6.9	1.8	1.31	27.0	9.16	3.33	0.16	0.20	13.75	0.11	0.05	.02	0.06	6.6	0.48
Lime + S.P. + Manure	7.1	1.8	1.26	25.8	10.51	2.90	0.26	0.20	14.56	0.30	0.03	.01	0.03	6.7	0.38
Lime + R.P. + Manure	6.7	1.3	1.21	21.6	10.55	3.15	0.24	0.24	13.81	0.12	0.01	.06	0.07	6.6	0.82
Lime + S.P.	6.7	1.2	1.06	21.0	10.51	2.29	0.17	0.24	13.12	0.11	0.02	.01	0.01	6.5	0.43
Control	5.7	1.3	1.05	31.6	6.62	3.12	0.17	0.19	13.75	0.11	0.06	.02	0.05	5.8	0.66

per acre of phosphorus which was quite high in comparison to the limed and fertilized plots. This was as was to be expected. Having produced but very poor crops, its supply of phosphorus was not depleted to the extent as was true in the case of plots that were limed and fertilized.

Exchangeable potassium was low in all plots. Even though potassium was low on all plots, it was interesting to note that plots receiving either muriate of potash or manure had a comparatively higher level of this element. This extra amount, admittedly small in magnitude, probably was very important in increasing the yields of crops.

The application of lime reflected an increase of at least 50 percent in the exchangeable calcium status of the limed and fertilized plots over the control plot. Exchangeable magnesium showed an upward trend on the plot that received a treatment of $MgSO_4 \cdot 7H_2O$. Exchangeable sodium was found to be low on all plots.

The magnitude of the cation exchange capacity of the soil samples showed that it was quite low as compared to many soils in other parts of the state. This was due to a very small amount of organic matter and the clay that existed in the soil.

The electrical conductivity data pointed out that there was no problem of salinity or alkalinity with the soil samples. The soluble cation contents were quite low.

DISCUSSION OF RESULTS

Examination of the data in Table 5 revealed several interesting and important points regarding the effect of various soil treatments in increasing the yield of soybeans. An increase of about two bushels per acre was brought about by liming the soil. This was as was to be expected. Cherokee silt loam, one of the most acidic soils in the state, needs an application of lime to decrease hydrogen ion concentration of the soil solution. This alteration tends to provide the best conditions for the healthy growth and development of nodule bacteria which fix the atmospheric nitrogen in the soil. Lime not only is beneficial due to its amelioration effect on the soil reaction and improving the nitrogen status, its effect is unique in other respects, too. For instance, lime stimulates plant growth due to its supplying of calcium ions to the soil. The carbohydrate and nitrogen relationship may be improved due to the effect of lime on the pH of the soil. Evidence was considerable in literature that lime increased the proteins and decreased the oil content of beans.

The addition of phosphate to lime in the soil treatment caused a further increase of three bushels. This beneficial effect of phosphate application could be attributed to better plant growth due to increased meristematic tissue development especially in the early period of growth of the soybean plant when phosphorus starvation might assume harmful proportions. A better protein synthesis seemed to have been promoted by the phosphate application. As the soybean seeds are rich in phosphorus, phosphates provided in the soil treatment could have promoted a more vigorous seed formation.

Soybeans gave best yields when potash in the form of muriate of potash or manure was included in the soil application. A greater number of pods per plant, greater degree of pod filling, greater seed weight and improvement of seed quality by a combined effect of potash and phosphates must have gone a long way in bringing about the desired effect. Potash application was also instrumental in improving the nitrogen status of the soil.

The apparent yield responses due to the applications of Mg, either in the form of magnesium sulfate heptahydrate, or that supplied in manure, could be attributed in part due to magnesium and possibly in part due to the beneficial effect of sulfur which also was present in these substances. Magnesium is a component of the chlorophyll molecule and also necessary in oil formation. Its presence seemed to have promoted nitrogen fixation. Sulfur is an important component of the protein molecule. It probably was a factor in promoting the growth of the crop by increasing the rate of nitrogen assimilation and consequently a healthier growth of stems and leaves. The combined effects and the interactions seemed to have provided very healthy environments to bring about the yield responses as were evidenced.

All these factor seemed to have been involved in the best treatment which included lime, superphosphate and manure; when a yield response of about 14 bushels per acre increase over the control plot was secured. Lime, superphosphate and manure treatment represented in itself a promise that could make possible an achievement of the goal of high yields with 500 pounds of oil per acre and 1,000 pounds of protein.

It is now a well established fact with the plant science that the concentration of nutrients in the cell sap of the plant determined the rate, the type of growth, and the activities related thereto. Modern soil science and plant physiology took it for granted that the concentraion of nutrients in the medium, be it soil or a culture solution, was important only to the extent to which the required nutrients were absorbed by the roots and further translocated to the parts where they were needed the most. The conception that the uptake of a certain nutrient ion stood in some simple relationship to its activity in the substrate was admittedly true in most cases. However, exceptions to the rule were not wanting when due to ion antagonisms or inter-relationships, certain unexpected situations emerged in this study. The correlation between the concentration of nutrient elements in soybean tissue and their proper balance playing a significant role in giving proportionate yield responses was obvious.

Magnesium and calcium were observed to be more abundant in the soybean cell contents than potassium in case of leaves, stems and roots in the second and third samplings, especially when $MgSO_4 \cdot 7H_2O$ was included in the treatment. This could be attributed to the fact that the level of potassium was low in southeastern Kansas soils. Sodium content was also low by the same token in the plant tissue. Whenever muriate of potash or manure was applied to serve as a source of potassium, the application of this element was reflected by a greater concentration in the cell sap.

The inter-relationships referred to above were examplified in the nitrogen accumulation when lime alone or potassium with lime were applied as part of the soil treatment. This was observed in the analytical data of soybean leaves. For instance, with the applications of lime alone, or lime, superphosphate and potash; an increase in the nitrogen accumulation was noted. With adequate calcium, application of phosphorus resulted in higher concentrations of the latter element in the plant tissues.

The concentrations of various nutrient ions in different parts of plant naturally varied. These concentrations changed from time to time in the different stages of life of the plant and translocations of nutrients form one part to the other were common. In the early stages of growth, the limited phosphorus accumulation by control plot plants induced a deficiency of phosphorus in all parts - roots, stems, and leaves, although the soil analysis showed that 31.6 pounds per acre of available phosphorus was present in the soil. This apparent anachronism can perhaps be explained by the fact that the phosphorus content of the control plot was comprised of organic and the clay-absorbed phosphorus which was not readily soluble in water and did not move enough in the soil to reach the young roots of soybean seedlings. Thus, only a small fraction of the available phosphorus in the control plot could be used. Whereas, in the plots that were given a dose of phosphates, enough soluble phosphorus in the soil solution was yielded to be readily available to the young plants. According to Bhangoo and Smith (5) the Cherokee silt loam surface soil had 260 pounds of organic P, 50 pounds of $Ca_3(PO_4)_2$, 100 pounds of absorbed P and 700 pounds of iron and aluminum phosphates per acre. Of all these sources only the small fraction in the form of calcium phosphate can be regarded as a ready source of soluble phosphate ions. Thus, a low availability of phosphorus under such conditions was to be expected. This is tantamount to saying that the amount of phosphorus accessible to the plant was proportional to the size of the root system and that time coincided with a period in the life of the plant when it needed to have all sources of available phosphorus at its disposal.

In the third sampling it was observed that the nitrogen content of leaves, stems and roots had undergone an appreciable decline. It was seen that while blossoms could be produced by the plant regardless of the nitrogen supplied to the plant, the processes of pod formation and retention were conditioned by it. The nitrogen needs of the plant were very acute at this stage and apparently the bulk of its supply was being translocated to the pods for a greater pod set, retention and filling.

In the same sampling, considerable accumulation of phosphorus by the pods and similarly of potassium was noted at the expense of the other parts of the plant. Both these nutrient elements were of critical importance to a profitable seed formation by the plant. A low level of nitrogen and phosphorus accumulation by the pods of the control plot was reflected in low yields. Evidently, there was a poor pod set and subsequently poor formation of seed.

SUMMARY AND CONCLUSIONS

An investigation of the nutritional requirements of soybeans was made on the crop grown on the Columbus Experimental Field in the year 1958.

At various stages of growth soybean plants were collected, separated into roots, stems, leaves and the pods in the last sampling and analyzed in the laboratory by standard analytical procedures. Soil samples, on which the crop was raised, were also analyzed to evaluate their fertility status, and for the purpose of observing trends to evaluate soil treatments. The experimental results suggested the following conclusions:

The soils of the area were generally low in fertility, quite acidic for soybeans unless limed, and low in potash and phosphorus supply, specifically. Cation exchange capacity was low, too.

Plant analyses reflected the greatest concentrations of potassium when either muriate of potash, or manure was included as a part of the soil treatment. An increase of at least four bushels per acre was secured, presumably, by potash application. The increased concentration of potassium in plant tissue and the increase in yield of soybeans brought about by its application suggested a need for the element.

Application of lime was of critical importance for the crop in southeastern Kansas, not only for effect on the soil reaction, but also for calcium fertilization and promotion of nitrogen fixation activities of bacteria. Lime application gave an increase of 2 bushels per acre.

Magnesium application usually produced greater magnesium content in the plant tissue. This was especially evident in earlier samplings. The treatment increased yields by 2 bushels per acre.

Plants in the control plots were conspicuous by their low phosphorus content, apparently exhibiting a phosphorus deficiency under such growth conditions. A three bushel increase was secured per acre by including phosphates in the treatment.

Nitrogen content of plant tissue produced on the unlimed plots was appreciably less that that of tissue produced on the limed plots, especially so in the last sampling. Presumably, the acid soil did not allow for efficient nitrogen fixation by nodule bacteria. Lime, apparently, also released substantial amounts of fixed phosphorus. At least, there was increased plant accumulation of phosphorus where only lime was added.

The best soil treatment was the one that had lime, superphosphate and manure. An increase of 14 bushels over the control plot was secured by its application.

In the plants the greatest accumulation of nitrogen was observed in the tops, its magnitude decreased toward the roots, where the accumulation was the least. In latter samplings, the nitrogen content was noted to decrease. Apparently, the plant requirements for the element were critically important at this stage.

Potassium content of the plant was translocated in a prominant measure into the pods, presumably for the requirement in seed formation in the latter stages of plant growth. This translocation of potassium to the seed of the soybean is different from what takes place in cereal plants. Thus, the great response of soybeans to potassium applied on this experiment field can possibly be accounted for in part by this particular translocation.

Phosphorus content of the pods increased at the time of seed formation at the expense of other parts.

Correlation between the potassium content and nitrogen accumulation was observed. An inverse relationship between calcium and magnesium uptake, and also between potassium and calcium and magnesium appeared to be a general pattern.

The accumulation of sodium was generally low and may be considered of little importance in the nutrition of soybeans.

The accumulation of any nutrient ion in the plant tissue was observed to depend on the time of sampling.

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NUTRITIONAL STUDIES WITH SOYBEANS

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Soybeans is an important crop in the United States. In Kansas, it is growing in popularity. The Kansas crop was worth five million dollars in 1957. Ninety-five percent of the area under the crop was in the first five tiers of counties in the east end of the state, south of the Kansas river.

But an acre yield of 11.5 bushels prevailing in this state with farming as a billion dollar business is too low to be profitable. To an agronomist this meant a challenge.

An investigation of the nutritional requirements of soybeans was undertaken in 1958 on the crop grown on the Columbus Experimental Field in southeastern Kansas. The study included thorough laboratory analyses of plant material produced in a field experiment that involved a variety of soil treatments. These treatments were compared to a control plot in respect to yield responses and the nutrient uptake by the plants.

Plants were collected in various stages of their growth from the field, separated into fractions constituting roots, stems and the leaves. In the third, and the last sampling, pods constituted another class. After drying, all samples were analyzed in the laboratory by standard procedures of chemical analysis. Soil samples, on which the crop was raised, were also analyzed to evaluate their fertility status. The experimental results suggested the following conclusions:

The soils of the area were generally low in fertility, quite acidic for soybeans unless limed, and low in potash and phosphorus supply, specifically. Cation exchange capacity was low, too.

Plant analyses reflected the greatest concentrations of potassium when either muriate of potash, or manure was included as a part of the soil treatment. An increase of at least four bushels per acre was secured, presumably, by potash application. The increased concentration of potassium in plant tissue and the increase in yield of soybeans brought about by its application suggested a need for the element.

Application of lime was of critical importance, for the crop in southeastern Kansas, not only for the effect on the soil reaction, but also for calcium fertilization, and promotion of activities of nitrogen fixing bacteria. Lime application gave an increase of 2 bushels per acre.

Magnesium application usually produced greater magnesium content in the plant tissue. This was especially evident in earlier samplings. The treatment increased yields by 2 bushels per acre.

Plants in the control plots were conspicuous by their low phosphorus content, apparently exhibiting a phosphorus deficiency under such growth conditions. A three bushel increase was secured per acre by including phosphates in the treatment.

Nitrogen content of plant tissue produced on the unlimed plots was appreciably less than that of the tissue produced on the limed plots, especially so in the last sampling. Presumably the acid soils do not allow for efficient nitrogen fixation by nodule bacteria. Lime, apparently, also released substantial amounts of fixed phosphorus. At least, there was increased plant accumulation of phosphorus where only lime was added.

The best soil treatment was the one that had lime, superphosphate and manure. An increase of 14 bushels over the control plot was secured by its application.

In the plants the greatest accumulation of nitrogen was observed in the tops, its magnitude decreased toward the roots, where the accumulation was the least. In latter samplings, the nitrogen content was noted to decrease. Apparently, the plant requirements for the element were of critical importance at this stage.

Potassium content of the plant was translocated in a prominent measure into the pods, presumably, for the requirement in seed formation in the latter stages of plant growth. This translocation of potassium to the seed of the soybean is different from what takes place in cereal plants. Thus, the great response of soybeans to potassium applied on this experiment field can possibly be accounted for in part by this particular translocation.

Phosphorus content of the pods increased at the time of seed formation at the expense of other parts.

Correlation between the potassium content and nitrogen accumulation was observed. An inverse relationship between calcium and magnesium uptake, and also b etween potassium and calcium and magnesium appeared to be a general pattern.

The accumulation of sodium was generally low and may be considered to be of little importance in the nutrition of soybeans.

The accumulation of any nutrient ion in the plant tissue varied with time of sampling.