# THE YIELD AND CHEMICAL COMPOSITION OF SOYBEANS AS AFFECTED BY WIDELY VARYING NUTRIENT LEVELS

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Aminul Islam

1962

This is to certify that the

thesis entitled

THE YIELD AND CHEMICAL COMPOSITION OF SOYBEANS AS AFFECTED BY WIDELY VARYING NUTRIENT LEVELS

presented by

Aminul Islam

has been accepted towards fulfillment of the requirements for

Ph.D. degree in Soil Science

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Date December 27, 1961

O-169

ABSTRACT

THE YIELD AND CHEMICAL COMPOSITION OF SOYBEANS AS AFFECTED BY WIDELY VARYING NUTRIENT LEVELS

by Aminul Islam

Soybeans which were fertilized with widely varying rates and combinations of nitrogen, phosphorus, potassium, calcium, and magnesium were grown on a Conover silt-loam soil in the field in 1960. In addition to seed yield determinations, the leaves and stems were harvested and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, total sugars, and amino nitrogen contents.

The use of nitrogen, phosphorus, and calcium increased seed yields, while the use of potassium or magnesium at moderate rates did not affect seed yields. At high rates, the use of these elements had a tendency to decrease yields.

The leaves contained more nitrogen, phosphorus, calcium, and magnesium than did the stems. The potassium content of the leaves was much lower than that found in the stem. At the flowering stage the leaves, in general, contained more total sugars and alpha amino nitrogen than did the stems.

The nitrogen levels in the leaves and the magnesium levels in the leaves and stems did not change greatly during the growing season. The nitrogen levels in the stems and

the potassium levels in the leaves decreased with time. Potassium in the stems increased until flowering time and then decreased. This also occurred with phosphorus levels in both the leaves and stems. The calcium levels in the leaves increased with time. The reverse occurred in the stems.

Nitrogen applied to the soil significantly increased the nitrogen content of both the leaves and the stems. This was associated with an increase in calcium and magnesium levels. The use of highly active nitrate ions accelerated the uptake of the less active calcium and magnesium ions.

The use of nitrogen resulted in lower total sugar and higher alpha amino nitrogen levels. This was probably due to the role that nitrogen plays in the formation of amino acid from alpha ketoglutaric acid.

The use of triple superphosphate resulted in increased accumulations of the divalent ions, calcium and magnesium. This was associated with lower levels of potassium. Differences in accumulation of cations by soybeans are attributed to the morphology and physiology of the roots.

The application of phosphorus increased the total sugar and alpha amino nitrogen content of soybean plants. Phosphorus is thought to increase the efficiency of carbon dioxide utilization. In addition this element is essential for phosphorylation reactions which could aid in the formation of alpha amino acids.

Potassium chloride applications to the soil resulted in an increase in potassium levels in both the stems and leaves. Lower levels of nitrogen in both the leaves and stems were found where potassium chloride was used. Heavy applications of potassium chloride apparently retarded nodule formation, thus decreasing the amount of nitrogen fixed. Magnesium levels in both leaves and stems were reduced with the application of potassium chloride. A high potassium to magnesium ratio in the soil was thought to be the reason.

Potassium chloride applied at rates up to 300 pounds per acre increased the total sugar content of both the leaves and the stems. At higher rates the quantity of total sugar was decreased. The explanation of this was related to the effect potassium has on the polymerization rate of sugar to starch or other complex carbohydrates. Low rates of polymerization were associated with low levels of potassium. Potassium also played an essential role in the synthesis of proteins from amino acids. This accounted for the observed decrease in amino acid content.

The effect of calcium hydroxide applications upon the calcium content of the leaves and stems was slight and not consistent.

The application of magnesium tended to increase the accumulation of phosphorus in soybean leaves. Magnesium seems to act as a carrier of phosphate. The application of magnesium decreased the concentration of potassium in the leaves and stems of soybeans. An antagonistic relationship between potassium and magnesium was observed.

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by

Aminul Islam

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Soil Science

1962

To My Parents

whose unfailing interest and constant encouragement have been a great source of inspiration, this thesis is affectionately dedicated.

## ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. K. Lawton, under whose supervision this work was initiated, for his interest, assistance, and guidance. The author is deeply indebted to Dr. L. S. Robertson for similar guidance and assistance in completing this work and preparing the manuscript.

Grateful thanks are extended to Dr. R. L. Cook who was entirely instrumental in getting the foreign student partial maintenance scholarship for the years 1960-61 and 1961-62. His constant support, encouragement and valuable suggestions in the preparation of the manuscript are highly appreciated.

Special thanks are due to Dr. A. R. Wolcott for his helpful suggestions concerning certain analytical and statistical procedures applicable to this study and to other members of the guidance committee, Prof. B. R. Churchill, Dr. H. C. Beeskow and Dr. G. P. Steinbauer (deceased) for their help and keen interest in the author's graduate program.

Life-long indebtedness is owed to all the teachers of Michigan State University from whom the author took courses. Their high standard of teaching, accompanied with unparalleled patience, constancy, assistance, sympathy, affection and friendliness will always be remembered.

The writer is thankful to Mr. C. Price for his assistance in conducting the field phases of this study and to his fellow graduate students for their cooperation and assistance at all times.

Finally, the fellowship offered to the author by the U. S. Fulbright Foundation and the financial assistance received from various sources through Michigan State University are gratefully acknowledged.

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# INTRODUCTION

It is widely recognized that the response of soybeans to direct fertilization is inconsistent. The average yield in the United States during the last 20 years shows little change. This is significant because other crops, especially corn, have shown a remarkable increase in yield per acre. A linear regression analysis, for the 1939-1959 period, indicates that corn yields increased one bushel per acre per year, while soybeans increased only one-fourth bushel for the same period (72).

As pointed out by Howell (45) and Ohlrogge (72) considerable study has been carried out in soybean nutrition with respect to growth, dry matter production, yield, and uptake of nutrients. However, much less information is available relative to interactions between applied fertilizers, native soil nutrients, and the root system characteristics of soybeans. There is very little in the literature on the effects of widely varying nutrient levels on the development of the soybean plant, especially where the levels resulted in a physiologic unbalance and a growth depression. Where nutrient level studies were conducted, the data collected were largely confined to absorption of mineral elements, and except for isolated greenhouse experiments, the nutrient levels were relatively low. Nitrogen applications seldom exceeded 100 pounds per acre (56, 70, and 100). Similarly, phosphate and potash additions to mineral soils generally fell in the range of 50 to 200 pounds of $P_2O_5$ or $K_2O$ per acre.

It is generally recognized by agronomists and plant physiologists that high levels in a growth medium of any single nutrient may depress the uptake of other nutrients. This in turn may upset the physiological process of assimilation, metabolism, and floral initiation (52). Accumulation of carbohydrates, proteins, and other organic constituents may be drastically altered. As a result, they may be in direct contrast to a more balanced nutrient environment (64). Thus, the many instances of ionic interactions and antagonism that may be possible are great (55, 86, and 91).

The purpose of this investigation was to study the effects of wide variations in soil nutrient content upon the chemical composition of soybeans grown under the complex variable environment of field conditions. More specifically, the research was designed to determine the influence of nitrogen, phosphorus, potassium, calcium, and magnesium singly and in combination on the dry matter production and the yield of soybeans. A further and more fundamental objective was to determine certain basic relationships which are operative in establishing variations in plant composition so that the result might be of value in interpreting data from similar studies in the future.

## REVIEW OF LITERATURE

Literature dealing with the effect of chemical fertilizers upon the accumulation of mineral elements and carbohydrate-nitrogen metabolism in crop plants is voluminous. This review, therefore, is restricted to the functions, interactions, accumulation, and redistribution of the elements nitrogen, phosphorus, potassium, calcium, and magnesium in soybean plants.

The review of literature is divided into six parts. The first five are related to each of the elements considered in this research, nitrogen, phosphorus, potassium, calcium, and magnesium. The sixth part deals with amino nitrogen and carbohydrate metabolism.

### Nitrogen

Differences in nitrogen content with respect to different parts of the soybean plant at various stages of development were recognized in the early nineteenth century. Webster (100) working on nitrogen metabolism of soybeans, reported that the leaves and stems, at an early stage of growth, contained as much as 8.0 per cent nitrogen. The concentration by blossom time decreased to 2.7 and 1.0 per cent, respectively, in the leaves and stems. Togari et al. (89) stated that for Japanese grown soybeans at the blooming stage, the leaves contained four times more nitrogen than the stems. Murneek (65) observed that the leaves and stems

of six-day old plants each contained about 9.0 per cent nitrogen. After 40 days of growth, these values decreased to 4.0 and 3.0, respectively, for leaves and stems. He aptly commented that the nitrogen contents of leaves and stems decreased with age. Erdman (26) working with inoculated soybeans grown under field conditions, found that in the early stages, there was a gradual decrease in per cent nitrogen. After 95 days, the per cent nitrogen increased and usually reached a maximum at maturity. The concentration differences in the plant parts became largest in the pod-filling stage. Hammond et al. (34) working with a problem of nutrient uptake by soybeans on Iowa soils, observed in mature plants, that the distribution of total nitrogen was 4.0 per cent in the stems and roots, 12.0 per cent in the leaves, and 4.0 per cent in the pods and 80.0 per cent in the seed.

Translocation of nitrogen from the cotyledons to the soybean seedlings is well understood. McAllister et al. (58) concluded that the concentration of protein in the cotyledons decreased with time. At emergence time, the cotyledons contained 70 per cent of the protein. Nine days later they contained only 25 per cent. At a still later date the concentration dropped to 7 per cent. Yoshira et al. (106) also observed that most of the nitrogen in the cotyledons was translocated to the seedlings during the first three weeks.

Hammond et al. (34) observed that during the period from the eighty-seventh day to the one hundred thirty-fifth day of maturity, the total nitrogen content of the plant increased 48 pounds per acre. However, the nitrogen content of the seed and pods increased to 121 pounds per acre. The nitrogen in the remainder of the plant decreased to 73 pounds per acre.

The rate of uptake of nitrogen by a soybean plant varies with the stage of growth. Analyses made by Hammond et al. (34) indicated that maximum absorption rate of 4.4 pounds per acre occurred during the seven-day interval between 94 and 101 days after planting.

Hampton et al. (35) working with the problem of influence of variable supplies of potassium and calcium on nitrogen fixation by soybeans found that plant growth and fixation of nitrogen were affected by the addition of both potassium and calcium. Higher levels of calcium stimulated nitrogen fixation to a greater extent than potassium. Potassium functioned chiefly in the production of carbohydrates. The influence of calcium on nitrogen fixation was more pronounced at lower than at higher levels of potassium. A low rate of potassium to calcium was necessary for maximum nitrogen fixation.

The need for applying nitrogenous fertilizers for higher yields is much debated. Investigators in Japan (106) reported that additional nitrogen, if needed, would be needed only during the first five weeks. They concluded that applications of nitrogen did not increase yields. Data from the investigations of Lathewell and Evans (50) showed that for maximum yields high levels of available nitrogen were necessary during the bloom period. The yield of beans was closely correlated with the amount of nitrogen accumulated throughout the life cycle. Allos et al. (4) studied the influence of increasing applications of available nitrogen (N-15) on growth and development. They observed that the fixation processes never supplied sufficient nitrogen for maximum growth and exhibited an apparent capacity to supply only one-half to three-fourths of the total nitrogen that could be used by the plant. The influence of seasonal variations in response of soybeans to additional nitrogen was observed by Lyons and Early (56). In 1947, which was warm and dry, marked yield responses to added nitrogen were obtained. The number of nodules per plant decreased 80 to 90 per cent, but there were appreciable increases in seed yields and in the nitrogen content of the seed. A year later with adequate rainfall, moderate temperatures, and 30 to 40 additional growing days, there was little to no response from added nitrogen. The number of nodules per plant on the untreated plot was larger than the previous year. The largest application of ammonium nitrate resulted in a 35 per cent decrease in the number of nodules.

The investigations carried out by Mederski et al. (61) and Lyons et al. (56) indicated that the use of lower rates of nitrogen resulted in an increase of two to four bushels of seed per acre, while the use of higher rates resulted in a yield depression.

Phosphorus

Extensive work has been completed on the utilization of phosphorus by soybeans. Phosphorus serves as a building material in the formation of nucleoproteins, flowers, and seeds. In greenhouse studies with sand cultures Mederski (60) showed that soybean leaves, stems, and total tops contained 0.69, 0.58, 0.65 per cent phosphorus, respectively. Forty days after planting, the upper leaves contained 0.74 per cent phosphorus and the lower leaves contained 1.6 per cent. At the same time the stem contained 0.76 per cent phosphorus, while the total aerial portion contained 1.05 per cent. At blossom time the concentrations were equal to 0.74 per cent in the upper leaves, 1.64 per cent in the lower leaves, 0.67 per cent in the stems, and 1.14 per cent phosphorus in the entire aerial portion of the plant. The per cent phosphorus for the same parts of the plant during the pod-filling stage were 0.76, 0.90, 0.53, 0.34, and 0.54. Mederski (60) reported that the concentration of phosphorus varied greatly between various parts of the soybean plant. The lower leaves acted as storage organs where excessive amounts of phosphorus were absorbed by the roots.

In a greenhouse experiment where magnesium levels were extremely low, Webb et al. (99) found the highest per cent phosphorus in mature plants. The leaves contained 1.03 per

cent, the petals, 0.75 per cent, the stem, 0.96 per cent, the roots 1.32 per cent, and the pods, 1.84 per cent phosphorus.

Maximal concentrations of phosphorus in field grown soybeans usually are much lower and frequently are equal to about one-half of those concentrations measured in nutrient solution studies. Wilkinson (104) using a band application of 40 + 160 + 0 in the field, found 0.5 per cent phosphorus in the tops of 42-day old soybean plants. The investigations carried out in the field by Borst et al. (10) in Ohio, Welch et al. (102) in North Carolina, Hammond et al. (34) in Iowa, Bureau et al. (15) in Ohio, and Togari et al. (89) in Japan, revealed that the most general range of concentration of phosphorus in soybean tops at the prebloom stage was between 0.25 and 0.30 per cent. From fertilizer tests with soybeans in Michigan, Austin (6) reported the highest value of 0.3 per cent phosphorus in the total tops of 73-day old plants.

Studies made by Merdeski (60) with solution culture experiments, indicated that minimal concentrations in the prebloom stage were 0.30, 0.15, and 0.25 per cent phosphorus for the leaves, stems, and total tops, respectively. Phosphorus concentrations decreased to .07 per cent in the upper leaves, 0.06 in the lower leaves, 0.03 in stems, 0.07 in the pods, and 0.05 in the total tops of soybeans at the mature stage. Mederski concluded that these would represent minimum values.

Minimal concentrations in field-grown soybeans may be

much lower. Bureau et al. (15) stated that with phosphorus deficient field-grown soybeans the concentration of phosphorus in the total tops during the prebloom stage was often less than 0.02 per cent. Matrone et al. (57) reported that at the blossom bud stage of field-grown soybeans the phosphorus concentrations ranged from 0.06 to 0.08 per cent in the stems and from 0.16 to 0.18 per cent in the leaves of plants grown on the "minus phosphate" plots.

Ohlrogge (72) in his article, "Mineral Nutrition of Soybeans" made a review of the cardinal concentrations of phosphorus in soybean plants. He stated, "Examination of numerous data suggests an optimum range for the total tops of between 0.25 and 0.45 per cent phosphorus for the prebloom stages. Higher concentrations would represent accumulations resulting from other factors limiting growth, and lower concentrations would represent inadequate phosphorus supplies or interference in phosphorus absorption." Ohlrogge (72) indicated that the most common concentrations reported at the bloom stage for soybeans grown on fertile soil was about 0.25 per cent phosphorus. He commented, "Consideration of all of the reported values indicates that concentrations between 0.25 and 0.35 per cent represent optimal nutrition, with values found above or below representing luxury consumption and deficiencies, respectively." Further, the critical concentrations for the tops exclusive of the seeds for mature soybeans, were 0.05 minimum, 0.25 to 0.35 optimum,

and 0.60 maximum (72).

The mobility of phosphorus in the plant was recognized early in the mid-1920's. Though Borst et al. (10) observed a decline in phosphorus concentration in leaves, stems, and pods of soybeans at the mature stage, they indicated that phosphorus moved only from the pod into the seed. McAllister et al. (58) reported that at emergence, 40 per cent of the phosphorus had translocated to the seedling from the cotyledons within the first 15 days. After 38 days, 75 to 90 per cent had migrated into the plant. A greenhouse study by Ohlrogge (72) indicated that low levels of mineral nutrition were correlated with early yellowing of the cotyledons, while high fertility levels delayed the yellowing. Investigations carried out by Mederski (60), Hammond et al. (34), Togari et al. (89) clearly indicated that 40 to 75 per cent of the phosphorus in the seed translocated from the pods, leaves, and stems. Hammond et al. (34) observed that the largest migration took place at low soil phosphorus levels. From an investigation on the effect of magnesium from phosphorus absorption and translocation in soybeans, Webb et al. (99) stated, "Omission of magnesium from nutrient solutions did not retard phosphorus absorption, but did have a significant effect upon the movement and final location of phosphorus in the plants. The chemical composition of the component parts revealed that magnesium deficient plants contained a higher percentage of phosphorus in the vegetative organs and a lower percentage in the seeds than in normal plants. A definite positive relationship existed between the magnesium and phosphorus content of the seed and a definite negative relationship between the content of these two elements in the leaflets. This finding offers support to the theory that magnesium acts as a carrier of phosphorus."

A different picture of phosphorus uptake by soybeans exists between field and nutrient culture experiments. The findings of Mederski (60) suggested an increased rate of uptake up to 50 days from planting and then a fairly constant rate until the leaves became yellow. Field experiments by Welch et al. (102), Hammond et al. (34), Bureau (15), and Wilkinson (104) demonstrated that a constantly increasing rate of phosphorus uptake occurred after the initial seedling lag and that a maximum rate of uptake of 0.40 pounds of phosphorus per day occurred during the pod filling stage. Hammond et al. (34) stated that the increasing rate of phosphorus uptake was a result of higher demands by the seeds.

With the advent of $P^{32}$, the contribution of fertilizer phosphorus could be easily estimated. However, the problem of not being able to consistently increase soybean seed yields with the application of phosphorus even on soils known to be low in available phosphorus still remains.

Colwell (18) in 1944 and Nelson et al. (67) in 1947, reported that soybeans responded to applications of phosphorus on many soils in the southeastern part of the United

States. The magnitude of yield increase was related to the level of available phosphorus in the soil. From a study on the utilization of fertilizer and soil phosphorus, using radioactive tracer techniques, Welch et al. (102) observed that the percentage of phosphorus derived from fertilizer was inversely related to the level of soil phosphorus and directly related to the rate of application. The total uptake was greater from high phosphorus soils. Early absorption of phosphorus was much higher when phosphorus was placed in bands than when it was broadcast and disked into the soil. Phosphorus applied to a previous crop was available to soybeans which were grown as a second crop. Increased production of dry matter, and in some instances of seed, was brought about by applications of phosphorus.

Krantz et al. (49) also found similar results. Much of the applied phosphorus was utilized in the later stages of growth.

Bureau et al. (15) from a study involving the use of $P^{32}$, made the following conclusions: "The phosphorus content of the plant was found to increase with an increase in the level of soil phosphorus and with the application of phosphatic fertilizers. The residual phosphate level appeared to influence the phosphorus content of the plant to a greater degree than did the application of phosphatic fertilizers. An increase in the level of soil phosphorus tended to produce larger quantities of dry matter, but showed an apparent depressing effect upon soybean yields."

Wilkinson et al. (104) in 1957 and 1958 noticed a consistent decline in the per cent of fertilizer derived phosphorus taken up during each stage of growth. There was no significant increase in seed yields, although a significant early response in dry weight and total phosphorus content of plants was obtained.

On reviewing the effect of phosphorus fertilizers on soybean yields and growth characteristics, Ohlrogge (72) aptly commented, "Certainly, a large part of the phosphorus can be derived from the fertilizer. Also, the total uptake of phosphorus may be and frequently is increased somewhat. There is, however, no assurance of an increase in yield. Thus, phosphorus does not appear to provide the exclusive key to unlocking the soybean mystery."

## Potassium

There has been a great amount of research both in the field and in the greenhouse on the role that potassium plays in the nutrition of soybeans.

From a greenhouse study Hutchings (46) reported that the total tops of soybeans at the prebloom stage contained as high as 5.70 per cent potassium. A study of the effect of varying concentrations in a nutrient medium led Allen (3) to report that total tops of the Virginia and Morse variety at the prebloom stage contained 2.7 and 3.5 per cent potassium. Evans et al. (27) observed a wide range of potassium concentrations in different parts of a flowering soybean

plant grown in sand cultures. The maximum concentration was 1.75 per cent potassium in the upper leaves. When the nutrient solution contained no magnesium the upper and lower leaves of soybean plants grown on complete solutions contained 0.84 and 0.60 per cent potassium, respectively.

Field studies carried out in Japan by Togari et al. (89) indicated that stems and leaves of soybeans at the prebloom stage contained more than 4.0 and 2.5 per cent potassium, respectively. At the onset of blooms, the total concentration of the top varied from 2.0 to 3.5 per cent potassium. Hammond et al. (34) reported a range between 1.0 and 1.5 per cent potassium in total tops at the prebloom stage. In the bloom stage the potassium concentration of the total tops ranged from 0.80 to 1.0 per cent while in the pod-filling stage the concentrations were between 0.5 and 0.7 per cent. Borst and Thatcher (10) after six years' investigation found that at the prebloom stage the leaves and stems contained 2.3 and 3.6 per cent potassium respectively. At the bloom stage total potassium concentration ranged between 0.9 and 1.2 per cent for the total tops. In the pod-filling stage the leaves declined from 1.0 per cent to 0.3 per cent, while the stem decreased from 0.8 to 0.3 per cent. They stated that the leaves and stems decreased in per cent potassium as the plants approached maturity.

From a nutrient culture experiment, Allen (3) reported a minimal concentration of 0.3 per cent potassium in the tops of plants at the prebloom stage. Evans et al. (27) reported a minimum of 0.18 per cent potassium in the lower leaves of soybeans at the blooming stage when plants were grown in solutions with toxic levels of magnesium. From a field study in Michigan, Austin (6) found that total tops of 35-day old plants contained 0.5 per cent potassium.

Ohlrogge (72) reviewed the cardinal concentrations of potassium in soybean plants. He stated that the data for the prebloom stage would suggest a minimum of 0.3 per cent, optimum range 1 to 4.0 and an upper limit of 5.7 per cent potassium for the total tops. For the blooming stage minimal optimal and maximum concentration in the tops of 0.3, 0.7 to 2.0, and 4.5 per cent potassium were suggested. During pod-filling stage the potassium in the stems ranged from over 3.0 to less than 0.3 per cent. The leaves ranged from 0.4 to 3.0 per cent and the pods from 0.8 to 3.0 per cent potassium.

The concentration of potassium at the onset of foliar deficiency symptoms was reported by Nelson et al. (66) from field experiments in North Carolina on a Coxville very fine sandy loam soil which was low in exchangeable potassium. The potassium content of the blade and petiole of leaves which showed foliar deficiency symptoms were 0.48 and 0.7 per cent. The levels in the normal leaves from the plots that received 120 pounds per acre of $K_2O$ were 2.1 and 1.6 per cent in the blade and petiole respectively.

The influences of cations upon the absorption of other cations represents a very complex phenomenon. Many plant cation relationships have been proposed. Evans et al. (27) observed that a deficiency of potassium in the nutrient solutions caused a decrease in potassium. A deficiency of magnesium increased the potassium content of soybean leaves twofold, whereas magnesium in toxic amounts caused the potassium contents of the leaves to decrease to near trace levels. A deficiency of phosphorus had a marked effect on increasing the potassium content of the leaves. Allen (3) noticed that with increasing supplies of calcium in the nutrient medium there was an increasing percentage of calcium and a decreasing percentage of potassium in the foliage. With an increasing supply of magnesium the per cent magnesium increased in the foliage and the potassium levels decreased.

The phenomenon of potassium translocation has been studied in detail. McAllister et al. (58) observed that a rapid loss of potassium from the colytedons occurred from planting until emergence. Then the rate decreased to the final level. One half of the potassium moved out of the cotyledons 15 days after planting. After 30 days, only 20 per cent of the original potassium remained in the cotyledons. From a nutrient free medium in a darkroom Von Ohlen (94) observed that in 25 days all of the potassium moved out of the cotyledons. Ohlrogge (72) commented that the extent of translocation would probably be dependent upon the potassium availability to the roots of the seedling.

Differences with respect to rate of uptake of potassium by soybeans exist in the literature. Hammond et al. (34) observed a peak rate of potassium uptake of 1.7 pounds per acre per day during a week period between 87 and 94 days after planting. They reported that potassium had shown more week to week variations in uptake rate than calcium, magnesium, nitrogen, or phosphorus. Togari's (89) results expressed on a per plant basis showed a much more constant trend. Results from six years' field experiments at Ohio by Borst and Thatcher (10) indicated a constantly decreasing rate of uptake during the pod-filling period.

Some of the most striking responses to fertilization have been obtained with potassium salts. Consistently large grain yield increases were obtained from potassium fertilizers on almost all of the potassium deficient soils of the south-eastern part of the United States when good production methods were used. In the Midwest, response has not been so consistent. Most of the responses were obtained on the sandier soils and on those prairie soils high in organic matter. The poorly drained light colored silt loams have not responded consistently to potassium applications even when potassium deficiencies were prevalent. Both broadcast and band applications of potassium resulted in increased levels of potassium in plants (72).

From a field experiment on a sandy loam soil low in

exchangeable potassium Nelson et al. (66) made the following summary:

1. Additions of potassium more than doubled the number of pods per plant of each variety, exerted a beneficial influence in retaining pods until harvest, resulted in an increase in the number of two-cavity sized pods and a decrease in the number of three-cavity sized pods. A significant influence was that of increasing the degree of filling.

2. Potassium markedly improved the seed quality by reducing the number of shriveled, shrunken, moldy, and off-colored seeds.

3. Maturity was retarded by additions of potassium.

4. Potassium increased seed weight of all varieties and the oil content of the seeds of two varieties out of three.

5. As an average of all varieties the addition of 60 pounds of $K_2O$ increased the yield fourfold.

Calcium

The beneficial effects of adequate quantities of calcium upon the structure of the soil, microbial activity, and the availability of other essential nutrients has been known for some time. The effect of various calcium levels upon soybean growth characteristics, however, is complex.

The investigations of Marston et al. (37), Hampton et al. (35), Allen (3), Graham et al. (30) and Brown et al. (14) with clay and sand cultures indicated that the calcium con-

tent of the total soybean plant at the prebloom stage ranged between 0.25 and 0.75 per cent.

Siegel (84) reported a range of 0.7 to 1.25 per cent calcium in soybeans that were grown in nutrient solutions.

At the prebloom stage Evans et al. (27) observed that the calcium concentration in the leaves of nutrient solution grown beans varied from near 0 to 6.5 per cent. The lower leaves contained 5.0 per cent while the upper leaves contained only 1.0 per cent. Studies in Japan by Hashimoto (40) showed that ranges in calcium content of the leaves and stems were between 0.5 and 1.5 and 0.3 and 1.14 per cent respectively. During the pod-filling stage as reported by Hashimoto (40) the leaves ranged between 2.0 and 2.4 and the stems between 0.7 and 1.6 per cent calcium. Field studies by Austin (6) showed that the calcium concentration of the total tops of soybean plants after 30 days from planting varied between 2.0 and 2.75. Hammond et al. (34) recorded concentrations of 1.9 and 1.25 per cent calcium in the total plant 22 and 55 days respectively after planting. In the study of Hashimoto et al. (41) the calcium concentrations ranged from 2.3 to 2.6 and 1.6 to 1.9 per cent in the leaves and stems of soybean plants at the preblossom stage. Wilkinson (104) reported that at the onset of flowers the calcium concentration of soybean tops varied from 0.5 to slightly higher than 1.0 per cent. Austin's (6) 73-day old plants ranged between 1.7 and 2.0 per cent calcium. Hashimoto et al. (42) reported a range of between 2.2 and 3.3, and 1.5 and 1.9 per cent calcium, respectively for leaves and stems at the blooming stage. In the pod-filling stage, Austin (6) found a range of between 1.2 and 2.0 per cent. Wilkinson (104) from a nutritional survey of farmers' fields found a range of between 0.9 and 4.5 per cent calcium. Ohlrogge (72) stated, "Here again, as is true for many other nutrients, the widest range in calcium content is found in the youngest plants."

The effect of complementary nutrients on the uptake of calcium has been studied. Evans et al. (27) noticed that a deficiency of potassium in a nutrient solution caused an increase in the uptake of calcium. Deficiencies of magnesium did not produce any change in the calcium concentration in the leaves whereas toxic quantities of magnesium caused the calcium content to decrease to a mere trace amount. Graham et al. (31) observed that the use of magnesium resulted in an increase in the uptake of calcium. Allen (3) found that an inverse relationship existed between the percent of potassium and calcium in the foliage, and with an increasing supply of magnesium there was little change in the calcium concentrations.

Translocation of calcium from cotyledons is almost absent. The investigation carried out by McAllister et al. (58) led to the conclusion that the calcium content did not change appreciably during seed germination. However, during

the 20 days after emergence, the calcium content of the cotyledons increased 300 per cent. The only discussion found on the rate of uptake was that made by Hammond et al. (34). He observed that the rate gradually increased, reaching a peak of 2.8 pounds of calcium per day for a week interval between 73 and 80 days after planting.

The immobility of calcium in soybean plants as stated by Ohlrogge (72) is well recognized. "This immobility lends increasing importance to gaining a complete understanding of the day-to-day requirements of the plant. The abundance and low cost of calcium has apparently discouraged research in calcium nutrition, but this does not preclude the possibility of a vital role for it as a factor limiting yields of soybean."

Ohlrogge (72) further commented, "Soybeans at low yield levels are unusually tolerant to soil acidity but do respond markedly to lime applications. A constant supply of calcium is required by the plant because of its immobility in the soybean. There are many other positive effects of liming, in addition to making calcium available to the plant. Since liming is a widespread practice on acid soil areas of the soybean belt, little work has been done to evaluate calcium as a nutrient in field soils."

<u>Magnesium</u>

Numerous greenhouse and field experiments have been designed to solve the mystery of the soybean yield plateau. Some of the research involved evaluations of the role of magnesium in the nutrition of soybeans.

From a nutrient culture study Allen (3) reported a range of 0.09 to 1.5 per cent magnesium in the leaves at the prebloom stage. Webb et al. (99) reported that at the onset of blooms the concentrations of magnesium in the total tops varied between 0.08 and 0.63 per cent. During the pod-filling stage Hashimoto (39) observed an equal concentration range for magnesium in the stems and leaves. The range varied between 0.2 and 0.6 per cent. The distribution and range of magnesium concentration in mature plants were evaluated by Webb et al. (99). They found that leaves varied between 0.05 and 0.68 per cent magnesium. Petioles varied between 0.03 and 0.56 per cent. The stems varied between 0.2 and 0.45 per cent. The roots varied between 0.06 and 0.53 per cent. The pods varied between 0.05 and 0.88 per cent. The seeds varied between 0.14 and 0.36 per cent and the whole plant varied between 0.06 and 0.53 per cent magnesium.

The field investigations of Austin (6) and Hammond et al. (34) showed a range of 0.27 and 0.80 per cent magnesium in the total tops of the soybeans at the prebloom stage. The highest concentration was 1.0 per cent magnesium in the tops of 73-day old plants (6).

The effect of complementary nutrients on the uptake of magnesium by soybeans has been noted. Studies on the chemical composition of soybeans grown under various nutrient conditions by Evans et al. (27) indicated that a deficiency of calcium in nutrient solutions caused an increase in the uptake of magnesium while increases in calcium in the nutrient solution apparently did not effect the magnesium uptake. Allen (3) noticed that with an increasing supply of calcium in the nutrient solution there was a decreasing percentage of magnesium in the foliage and also an inverse relationship between the percentages of potassium and magnesium.

The content of magnesium associated with the onset of foliar deficiency symptoms was reported by a number of investigators. Webb et al. (99) observed a concentration of 0.09 per cent magnesium in the tops of soybean plants which showed magnesium deficiency symptoms at the prebloom stage. Hashimoto (39) suggested that at the onset of foliar deficiency symptoms field grown soybean plants contained 0.10 per cent magnesium. Webb et al. (99) further suggested that the onset of deficiency symptoms in the leaves of flowering plants was associated with a magnesium concentration of 0.25 per cent for all of the leaves of the plant. The leaves of the normal plant had a concentration of more than 0.3 per cent magnesium.

The translocation of magnesium from cotyledons is much less than for nitrogen, phosphorus, and potassium. McAllister et al. (58) observed that from germination to emergency only one-fourth of the magnesium moved out of the cotyledons. This was in contrast with almost complete removal of potassium and phosphorus and no removal of calcium. Again, like calcium the cotyledons gained magnesium from the 28th to the

37th day, but the magnitude was much lower than for calcium. Hammond et al. (34) noticed a gradual increase in the uptake of magnesium which reached a maximum absorption rate of 1.5 pounds per acre per day during the interval of 37 to 80 days after planting. Data from the nutrient culture experiment of Webb et al. (99) indicated a peak uptake of five milligrams per plant per day for a five-day period between the 65th and 70th day after planting.

From a study of chelated, exchangeable and readily soluble magnesium as factors in the nutrition of soybeans Graham et al. (31) concluded that on 11 of the 15 soils yield increases occurred when magnesium was added to the soil. The highest correlation between the amount of magnesium shown by soil tests and per cent increase in crop yield was obtained when the soil was extracted with 0.05 normal hydrochloric acid. In general, the soils with less than 10 per cent magnesium saturation of the total exchange capacity were the ones where yield responses to the nutrient were obtained. This fact re-enforced the suggestion that the 10 per cent level would be a helpful guide when attempting to determine a desirable magnesium level in the soil. Nelson et al. (66) obtained an increase of seven bushels per acre by the use of 36 pounds of magnesium oxide per acre on a soil low in exchangeable magnesium.

Amino Nitrogen and Carbohydrate Metabolism

There are not as many publications on amino nitrogen and carbohydrate metabolism in soybeans as there are on direct utilization of mineral elements by this crop. Therefore, this section includes comments on research completed on other crops as well as soybeans.

Scruti (79) determined that phosphorus played an important role in the formation of amino acids.

In studying the effects of various mineral deficiencies on nitrogen metabolism, Burrell (16) observed that the leaves and stems of magnesium deficient plants contained smaller amounts of starch and insoluble nitrogen as well as larger quantities of soluble nitrogen than did the leaves and stems of the control plants. With potassium deficient plants, he observed that the leaves accumulated starch. The amino nitrogen was usually high. He concluded, "Potassium seems to function in the translocation and utilization of starch and is especially important in the formation of protein and carbohydrates." In calcium deficient plants he noted that the leaves accumulated nitrate nitrogen. The amino nitrogen content, however, was lower. He concluded, "Calcium may play some important role in nitrate reduction."

Nightingale et al.(68) attributed the following functions to potassium:

1. Potassium appears to be directly or indirectly essential for carbon dioxide assimilation and therefore

concentrations of carbohydrates may be low in potassium deficient plants.

2. Carbohydrates frequently accumulate in potassium deficient plants apparently because the rate of nitrate assimilation is retarded.

3. Potassium appears to be directly or indirectly essential for the initial stage in nitrate reduction.

4. Potassium is directly essential for the synthesis of protein in the meristematic tissue.

Janssen et al. (47) working with cowpeas grown in nutrient solutions reported that plants grown with low levels of potassium contained more reducing sugars as well as total sugars. Also they contained smaller quantities of starch than those grown with high levels of potassium. The nitrogen content was usually greater in "low potassium" plants than in "high potassium" plants. In nearly all instances the per cent amino nitrogen was greater in plants which contained low levels of potassium than in those which contained high levels.

Nightingale et al.(69) observed that calcium deficient tomatoes grown in a greenhouse failed to absorb nitrate. After calcium was added to the nutrient solution which originally contained no calcium, absorption started instantly. After only a few hours nitrate nitrogen was absorbed and growth was resumed.

Phillips et al. (73) observed that the potassium deficient leaves of tomato plants were high in reducing

sugars as well as insoluble nitrogen. Janssen et al. (48) also working with tomatoes found that the protein content was somewhat proportional to the level of nitrogen in the nutrient solution. They also observed that a deficiency of potassium caused an accumulation of amino nitrogen. The amounts of reducing and total sugars were approximately proportional to the amount of dry matter produced.

Haart (38) reported that the blades and the stems of potassium starved sugar cane contained high quantities of amino nitrogen and reducing sugars. The blades and stems also contained lower quantities of protein and sucrose than did those of control plants. The total sugar however remained the same. He concluded that the synthesis of protein was diminished in plants grown at low potassium levels. "A potassium deficiency resulted in de-rearrangements in the transformation of hexoses and sucrose."

Gregory et al. (32) working with barley found that a nitrogen deficiency had no consistent effect on the quantity of free reducing sugars even though the quantity of total sugars increased. A phosphorus deficiency increased the free reducing sugars. Total sugars were not greatly affected. A potassium deficiency lowered the quantity of free reducing sugars as well as the total sugar content.

Other studies with barley by Gregory and Sen (33) suggested that potassium deficiencies led to a reduction in the total sugar concentrations within the plant. The total

protein was decreased while the amino nitrogen content increased. A nitrogen deficiency led to a greatly increased sugar level and a reduced protein and amino nitrogen level.

Wall (95) stated that a deficiency of potassium "seems to curtail protein synthesis and this seems to occur in the stage amino acid-protein after amino acids have been formed." In another project he (96) further noticed that potassium deficient plants accumulated ammonia, amide, and amino nitrogen, while the protein content decreased. He concluded that the results demonstrated that the protein synthesis from an "elaborated form" of nitrogen was affected by a potassium deficiency.

# EXPERIMENTAL METHODS

## Field Studies

A field experiment was initiated in 1960 on the Soil Science farm of Michigan State University on a medium fertile Conover silt loam soil. The purpose of the experiment was to determine the effect of wide ranges in rates and combinations of nitrogen, phosphorus, potassium, calcium and magnesium applied to the soil on the status of certain inorganic and organic constituents of soybeans at various stages of development. A total of 63 treatments were used. Each treatment was replicated 3 times. Each plot was 10 feet wide and 25 feet long and contained 4 rows.

The fertilizer materials included ammonium nitrate, 33.5 per cent nitrogen; triple super phosphate, 45 per cent $P_2O_5$; potassium chloride, 60 per cent $K_2O$; calcium hydroxide, 54 per cent calcium; and magnesium oxide, 60 per cent magnesium. The 5 nutrient levels, expressed on an elemental basis, including the zero level and the rates of application used in this experiment are shown in Table 1.

Each nutrient was accompanied by other nutrients at what was considered to be "low," "medium," and "high" levels. One-half of the fertilizer and lime were broadcast before plowing on May 14 and 15, and the other half after plowing on June 4 and 5. The materials were worked into the top 3 or 4 inches of soil.

Inoculated Chippewa soybeans were planted on June 25 in 28 inch rows at the rate of 60 pounds of seed per acre. The middle 2 rows were harvested by hand for seed yield evaluations on October 20 and 21.

Soil samples were taken from each plot before and after the application of fertilizer. Each sample represented a composite of 15 cores which were taken to a depth of 8 inches.

Plants were selected at random from the middle 2 rows on July 12 when the plants were 13 days old, on July 25 when the plants were 26 days old, and on August 3 when the plants were 34 days old, August 11 when the plants were 42 days old, August 30 when the plants were 61 days old, and on September 13 when the plants were 74 days old. The number of plants harvested from each plot on the different dates were 30, 30, 20, 10, 10, and 10, respectively. The plants were cut off at the ground level. On the third sampling date, 10 plants were frozen immediately after sampling.

## Laboratory Studies

### Soil Analyses

The soil samples obtained from each plot were air dried and screened through a 2 millimeter sieve. After mixing, 200 gram samples of soil from each plot were saved for chemical tests.

The pH of each sample was evaluated with a Beckman potentiometer using a 1 to 1 soil water ratio.

Available phosphorus was determined by the method of Bray (12). The extracting solution consisted of 0.03 normal ammonium fluoride and 0.025 normal hydrochloric acid. A soil extracting solution ratio of 1 to 8 was used.

Exchangeable potassium, calcium, and magnesium evaluations were made by leaching the soil with neutral ammonium acetate. A soil extract ratio of 1 to 10 was used. Determinations for potassium and calcium were made with a Coleman model 21 flame photometer. A Beckman model D. U. flame photometer was used in evaluating the magnesium content.

Plant Analyses

All plant samples were separated into 3 parts, leaves, stems, and pods when present. These were oven dried at 140° Fahrenheit, weighed, and then ground in a Wiley mill. Samples of July 12, August 3, and August 30 were used in determining the elemental composition of the leaves and stems of the soybean plants.

Values for total nitrogen were obtained with the Kjeldahl method as outlined by Pierce and Haenisch (74) and later modified by Prince (77). Samples of the plant material were wet digested with nitric and perchloric acid as outlined by Piper (75). The crystalline residue was dissolved in 0.05 normal hydrochloric acid, filtered and diluted to a known volume. The phosphorus content was measured with the ammonium molybdate--colorimetric procedure as outlined by Fiske and Subarrow (28). Magnesium was determined by a thiazole yellow technique outlined by Drosdoff and Nearpass (22). Potassium and calcium concentrations were evaluated using a Coleman model 21 flame photometer.

In the sugar and amino nitrogen determinations, plant tissue was ground in a Waring blender to which alcohol and calcium carbonate were added. The filtered extract was heated immediately to stop all enzymatic activity. The material was finally evaporated to dryness. The residue was then dissolved in a known volume of water. Alpha amino nitrogen was determined with the nin hydrin colorimetric method developed by Harding and McLean (36). Total sugars were estimated by the use of the picrimate colorimetric technique developed by Thomas and Dutcher (87).

Table 1. - Rates of elements used in the field experiment on soybeans.

| | Level and Rate of Application in Pounds per Acre | | | | |
|---|---|---|---|---|---|
| Element | 0 | 1 | 2 | 3 | 4 |
| N | 0 | 50 | 100 | 200 | 400 |
| P | 0 | 50 | 100 | 200 | 400 |
| K | 0 | 150 | 300 | 600 | 1200 |
| Ca | 0 | 800 | 1600 | 3200 | 6400 |
| Mg | 0 | 100 | 200 | 400 | 800 |

# RESULTS AND DISCUSSION

The nitrogen, phosphorus, potassium, calcium, and magnesium content of both leaves and stems of soybeans which were collected at three stages of plant development, the total sugar and amino nitrogen content of both leaves and stems at the flowering stage, and the yield are summarized in Tables 2 through 46.

The average effects of a given nutrient level associated with the various levels of a specific nutrient are included with this discussion. Therefore, this discussion is divided into five major sections; each section describes the results that were obtained from the use of one of the nutrients used in this project. Each section is subdivided into four parts: 1) soil nutrient contents as measured with chemical soil tests; 2) crop yields as the dry weight of the soybean leaves, stems, and seed; 3) the chemical composition of the leaves and stems; and 4) a discussion of results.

In order to facilitate discussion, the data have been keyed; the rates of application of the various nutrients are numbered from 0 to 4 as is described in Table No. 1. For example, N-0 refers to no nitrogen; N-1 to 50 pounds per acre or level 1 of nitrogen; P-2 to 100 pounds per acre or level 2 of phosporus; K-3 to 600 pounds per acre or level 3 of potassium; and so on.

The term "complementary nutrients" is used to describe the general level of application of nitrogen, phosphorus, potassium, calcium, and magnesium when one of these elements is omitted or is evaluated at different levels.

The complementary nutrients are considered at three levels: low, medium, or high. The word "low" is used to indicate a zero level of all nutrients except one. The effect of this one element is then evaluated at each of the five levels of application.

The word "medium" denotes the second level of all nutrients except one. This is equivalent to 100, 100, 300, 1,600, and 200 pounds per acre of nitrogen, phosphorus, potassium, calcium, and magnesium respectively.

"High" represents the highest level of application of each of these nutrients. This is equivalent to 400, 400, 1,200, 6,400 and 800 pounds per acre of nitrogen, phosphorus, potassium, calcium, and magnesium respectively.

The symbol C-0 refers to an average of the five levels of a given treatment within the low group of complementary nutrients. For example: C-0 (N) denotes an average of all the nitrogen treatments when the complementary treatments were at the zero level; C-2(N) represents an average of all of the nitrogen treatments when the complementary nutrients were held constant at the medium level; C-4(N) represents an average of the nitrogen treatments when the complementary nutrients were maintained at the high level.

The average for a particular rate of application of a single nutrient at three complementary levels—low, medium, and high—is designated by the symbol of the element and the number that represents the level of the treatment. For example: N-3 is the symbol used to indicate an average of all the treatments that receive 200 pounds of nitrogen per acre which is the third level of applied nitrogen.

Below the value reported in each table are one or more letters. These symbols are ranges of equivalence as defined by Duncan (23). Within columns of these tables numerical values with the same letters below them are not statistically different at the 5 per cent level.

Soil Nutrient Levels, Crop Yields, and the Chemical Composition of Soybean Plants as Affected by Three Levels of Complementary Nutrients Associated with Five Levels of Nitrogen.

Soil Nutrient Contents.

Soil samples were collected from each plot before fertilizer was applied. Analyses of the soil test results, while not included in this thesis, showed a wide range in results, especially in regard to the calcium and magnesium results.

Soil samples were again taken and tests made six weeks after the fertilizer and lime were applied. A summary of the soil test results as related to the three levels of complementary nutrients and associated with the five levels of nitrogen is shown in Table 2. As would be expected, the use of complementary nutrients increased the level of each element. The five levels of nitrogen did not effect the pH level or the level of phosphorus or potassium. The variation associated with the calcium and magnesium results probably reflect original differences from plot to plot in each of these elements.

Crop Yield.

The average leaf and stem yields at three stages of development are shown in Table 3. On July 12 the plants

were thirteen days old and reflected the effect of the use of complementary nutrients by a reduction in the weight of both leaves and stems. After this date either the difference disappeared or the sample size was not adequate to evaluate the differences in the weights of the leaves and stems. On the first sampling date, the use of nitrogen at the higher rates resulted in a general decrease in weight of both the leaves and stems. However, at blossom time and at pod-forming time these differences were not evident; in fact, while the values statistically are similar, the data suggest an increase in the weight of both leaves and stems caused by the use of nitrogen.

The soybean seed yields are summarized in Table 4. A five-bushel per acre increase in seed yield was obtained where the second level of complementary nutrients was used. At the high complementary nutrient level, yields dropped to a position below that obtained where only nitrogen was used. The general effect of nitrogen was to increase the yields slightly. The highest yields were obtained where the three highest rates of nitrogen were used.

Chemical Composition.

The nitrogen content of the leaves and stems are summarized in Table 5. The leaves contained a higher percentage nitrogen than did the stems. The nitrogen content of the leaves did not vary greatly during the season. The level was highest on August 3 and then decreased during the pod-filling stage. The levels in the stems decreased with each sampling.

The use of complementary nutrients decreased the nitrogen level in both the leaves and the stems with one exception. The first level significantly increased the nitrogen content of the stems on the first sampling date.

Nitrogen fertilizers generally increased the nitrogen levels in both the leaves and the stems except on the second sampling of the leaves. At this time the values for per cent nitrogen were relatively similar.

The phosphorus levels in the soybean leaves and stems are summarized in Table 6. The phosphorus levels in both the stems and the leaves, generally speaking, increased during the flowering stage and decreased during the pod-forming stage. With one exception, the average phosphorus levels in the leaves were higher than in the stems.

In the leaves the use of complementary nutrients increased the phosphorus levels even though on the second sampling date the increase was not statistically significant. This was also the situation in the stems.

The use of nitrogen did not affect the phosphorus content except on the first sampling date. In the leaves sampled on July 12, the variation did not suggest a trend; in the stems the use of increased quantities of nitrogen fertilizer were associated with slightly lower phosphorus levels.

The potassium contents of both stems and leaves are shown in Table 7. In most instances the stems contained the highest per cent potassium. The potassium content of the leaves decreased with each sampling. In the stems the potassium content increased during the flowering stage and then decreased to a level below that found on the first sampling.

The use of complementary nutrients increased the potassium content of both the stems and the leaves. The use of nitrogen had a tendency to decrease the potassium content of both the leaves and the stems on the first sampling date but only that of the leaves on the second sampling date. By pod-forming time, no statistically different values were obtained.

The average calcium content of both leaves and stems is shown in Table 8. The calcium levels of the leaves increased with maturity of the plants. In the stems, especially after the blossom stage, calcium levels decreased at a rapid rate. In the leaves, the calcium levels generally decreased where the complementary nutrients were used while in the stems, the use of the first level of complementary nutrients caused an increase. On August 3 and 30, differences in calcium levels were neither consistent nor statistically significant.

The use of nitrogen, especially at the highest levels on July 12, had a general effect of increasing the calcium levels in both the leaves and the stems. This was less evident in samples collected on August 3. No statistically

different values were obtained from samples collected on August 30.

The average magnesium levels are shown in Table 9. The stems did not contain as much magnesium as did the leaves. In the leaves, the magnesium levels were highest during the blossom stage. With one exception this was not the situation in the stems. The use of complementary nutrients greatly decreased the magnesium levels in both the leaves and the stems. On the first sampling date, the use of nitrogen increased the magnesium levels in both the leaves and the stems. By August 30 no statistically different levels in magnesium were measured.

The average total sugar and amino nitrogen contents of soybean leaves and stems at the flowering stage are shown in Table 10. The sugar content percentages of the leaves were much higher than those of the stems. In both parts of the plant, the highest levels of sugar were obtained at the second level of complementary nutrients. The inclusion of nitrogen in the fertilizer had the general effect of lowering the sugar levels in the leaves and the stems.

With one exception, the leaves contained more amino nitrogen where the highest rate of nitrogen was used. The complementary nutrients decreased the amino nitrogen levels while the use of nitrogen increased the amino nitrogen levels. The highest levels in the leaves were obtained at N-2 where 100 pounds of nitrogen had been used while the highest level in the stems was obtained at N-4 where 400 pounds of nitrogen had been used.

Discussion.

Soil test results increased with levels of applied phosphorus, potassium, calcium, and magnesium. Soybean yields were increased approximately five bushels per acre as a result of using the complementary nutrients up to the second level, C-2. Beyond this level, yields fell rapidly; thus reflecting an unbalanced nutrient status or a toxic level of nutrients in the soil.

In this experiment soybeans responded to the use of nitrogen in combination with the complementary nutrients. This is not unusual. Wilson (105) theorizes that when photosynthesis occurs at a high rate, it is difficult for nitrogen to be fixed at a sufficiently rapid rate. Under these conditions the use of extra nitrogen in the soil would be helpful in increasing plant growth. Others in both field and greenhouse experiments showed that the amount of nitrogen fixed by soybeans may sometimes be inadequate to supply the nitrogen needs of the plant (25, 34, 70, 71, 88).

The data suggest that the use of nitrogen had a tendency to increase the uptake of calcium and magnesium. This was more evident early in the season. Brooks (13) and Hoagland et al. (44), working with several crops, noted a similar situation. They (44) stated that, "The rate of accumulation of the anion was conditioned primarily by the presence in suitable concentration of a cation capable of ready penetration and accumulation rather than upon alterations in the protoplasm resulting from different proportions of mono and divalent ions." They also postulated that there was a definite competition between ions of the same charge. The more active ions repressed the accumulations of the less active ions. Also the more active anions accelerated the uptake and accumulations of the less active cations. According to the rates of penetration, Seifriz (80) listed the order of uptake of cation as follows: potassium greater than magnesium and magnesium greater than calcium. In regard to the anions he found nitrate to be greater than phosphate and phosphate greater than sulfate.

The general effect of nitrogen was to decrease the total sugar content of leaves and stems but to increase the content of the alpha amino nitrogen. Welton and Morris (103) stated in their work with soybeans that, "Heavy applications of nitrate tended to inhibit the accumulation of carbohydrates."

The increases in alpha amino nitrogen and the decrease in total sugars suggest that nitrogen may exert an influence on the Krebs cycle in the formation of alpha ketoglutaric acid. This compound, after reacting with ammonia reduced from nitrate, forms amino acid. Further applications of nitrogen tended to reduce the uptake of potassium which played an essential role in the synthesis of proteins from amino acids. Therefore, the accumulation of amino acids would be possible.

Table 2. - Average soil test results as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment | | Available soil nutrients | | | | |
|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Soil Reaction | Pounds Per Acre | | | |
| | | | Phosphorus | Potassium | Calcium | Magnesium |
| C-0(N) | - | 6.9 b | 31 c | 90 c | 2683 c | 866 c |
| C-2(N) | - | 7.4 a | 53 b | 131 b | 3807 b | 998 b |
| C-4(N) | - | 7.4 a | 104 a | 355 a | 5100 a | 1040 a |
| N-0 | 0 | 7.2 a | 61 a | 201 a | 4044 a | 1023 a |
| N-1 | 50 | 7.3 a | 70 a | 201 a | 3850 ab | 890 b |
| N-2 | 100 | 7.2 a | 67 a | 194 a | 3917 ab | 993 a |
| N-3 | 200 | 7.2 a | 54 a | 172 a | 3844 ab | 920 b |
| N-4 | 400 | 7.1 a | 63 a | 191 a | 3660 b | 1013 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 3. - Average leaf and stem yields of soybeans at three stages of development as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment | | Dry Weight of 10 Plants (gms) | | | | | |
|---|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Leaves | | | Stems | | |
| | | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(N) | - | 1.96 a | 11.9 a | 65.4 a | 0.84 a | 6.8 a | 62.6 a |
| C-2(N) | - | 1.81 c | 13.4 a | 71.1 a | 0.82 b | 8.0 a | 69.3 a |
| C-4(N) | - | 1.84 b | 11.5 a | 65.0 a | 0.84 a | 7.0 a | 61.5 a |
| N-0 | 0 | 1.91 a | 12.2 a | 56.2 a | 0.87 a | 7.5 a | 56.3 a |
| N-1 | 50 | 1.93 a | 11.4 a | 63.5 a | 0.83 bc | 7.0 a | 61.1 a |
| N-2 | 100 | 1.88 b | 12.6 a | 68.7 a | 0.84 b | 7.1 a | 66.1 a |
| N-3 | 200 | 1.89 b | 13.1 a | 76.9 a | 0.82 c | 7.8 a | 73.2 a |
| N-4 | 400 | 1.73 c | 12.1 a | 70.4 a | 0.80 d | 7.0 a | 65.6 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 4. - Average soybean seed yields as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Yield Per Acre (Bushels) |
|---|---|---|
| C-0(N) | - | 22.5 b |
| C-2(N) | - | 27.8 a |
| C-4(N) | - | 21.2 b |
| N-0 | 0 | 21.0 c |
| N-1 | 50 | 23.2 b |
| N-2 | 100 | 24.8 ab |
| N-3 | 200 | 25.9 a |
| N-4 | 400 | 24.2 ab |

C - Complementary nutrients - P, K, Ca and Mg

Table 5. - Average nitrogen content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Nitrogen in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(N) | - | 5.27 a | 5.57 a | 5.12 a | 3.23 b | 3.01 a | 2.49 a |
| C-2(N) | - | 5.01 b | 5.41 a | 4.83 b | 3.37 a | 2.57 b | 2.20 b |
| C-4(N) | - | 4.77 c | 5.36 a | 4.93 b | 3.04 c | 2.36 c | 2.27 b |
| N-0 | 0 | 4.41 c | 5.48 a | 4.51 c | 2.45 d | 2.33 c | 1.78 c |
| N-1 | 50 | 5.06 b | 5.31 a | 4.76 bc | 3.06 c | 2.44 c | 1.94 bc |
| N-2 | 100 | 5.29 a | 5.49 a | 4.84 b | 3.53 ab | 2.69 b | 2.19 b |
| N-3 | 200 | 5.01 b | 5.54 a | 5.23 a | 3.47 b | 2.85 a | 2.72 a |
| N-4 | 400 | 5.34 a | 5.40 a | 5.45 a | 3.55 a | 2.90 a | 2.97 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 6. - Average phosphorus content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Phosphorus in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(N) | - | 0.237 b | 0.411 a | 0.258 c | 0.193 c | 0.216 a | 0.153 b |
| C-2(N) | - | 0.254 a | 0.432 a | 0.297 b | 0.231 a | 0.232 a | 0.202 a |
| C-4(N) | - | 0.258 a | 0.429 a | 0.342 a | 0.212 b | 0.247 a | 0.212 a |
| N-0 | 0 | 0.281 a | 0.429 a | 0.294 a | 0.228 a | 0.231 a | 0.178 a |
| N-1 | 50 | 0.184 d | 0.412 a | 0.318 a | 0.214 b | 0.242 a | 0.186 a |
| N-2 | 100 | 0.285 a | 0.431 a | 0.314 a | 0.208 b | 0.232 a | 0.198 a |
| N-3 | 200 | 0.235 c | 0.425 a | 0.284 a | 0.209 b | 0.232 a | 0.189 a |
| N-4 | 400 | 0.263 b | 0.421 a | 0.286 a | 0.200 c | 0.221 a | 0.194 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 7. - Average potassium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment | | Potassium in Soybean Tissue (per cent) | | | | | |
|---|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Leaves | | | Stems | | |
| | | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(N) | - | 1.66 c | 1.33 b | 1.15 b | 1.53 c | 1.94 c | 1.15 c |
| C-2(N) | - | 2.40 b | 1.94 a | 1.59 a | 2.89 b | 3.40 b | 2.05 b |
| C-4(N) | - | 2.52 a | 2.00 a | 1.66 a | 3.52 a | 3.99 a | 2.41 a |
| N-0 | 0 | 2.55 a | 1.84 a | 1.46 a | 3.15 a | 3.30 a | 1.94 a |
| N-1 | 50 | 2.15 bc | 1.82 ab | 1.42 a | 2.50 c | 3.20 a | 1.78 a |
| N-2 | 100 | 1.99 d | 1.73 b | 1.44 a | 2.52 c | 3.02 a | 1.82 a |
| N-3 | 200 | 2.17 b | 1.68 b | 1.47 a | 2.65 b | 2.96 a | 1.80 a |
| N-4 | 400 | 2.09 c | 1.73 b | 1.52 a | 2.40 d | 3.07 a | 1.99 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 8. - Average calcium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment | | Calcium in Soybean Tissue (per cent) | | | | | |
|---|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Leaves | | | Stems | | |
| | | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(N) | - | 1.53 a | 1.72 a | 1.79 a | 1.58 c | 1.60 a | 0.99 a |
| C-2(N) | - | 1.36 b | 1.68 ab | 1.67 b | 1.69 a | 1.57 a | 1.04 a |
| C-4(N) | - | 1.37 b | 1.63 b | 1.74 ab | 1.61 b | 1.61 a | 1.03 a |
| N-0 | 0 | 1.28 d | 1.62 b | 1.70 a | 1.52 d | 1.56 b | 1.02 a |
| N-1 | 50 | 1.37 c | 1.65 b | 1.74 a | 1.68 a | 1.55 b | 0.99 a |
| N-2 | 100 | 1.46 b | 1.70 ab | 1.75 a | 1.65 bc | 1.61 ab | 1.02 a |
| N-3 | 200 | 1.49 ab | 1.67 ab | 1.72 a | 1.63 c | 1.54 b | 1.01 a |
| N-4 | 400 | 1.50 a | 1.75 a | 1.77 a | 1.66 ab | 1.71 a | 1.06 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 9. - Average magnesium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Magnesium in Soybean Tissue (per cent): Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-O(N) | - | 0.535 a | 0.729 a | 0.672 a | 0.376 a | 0.539 a | 0.519 a |
| C-2(N) | - | 0.445 b | 0.454 b | 0.442 b | 0.340 b | 0.301 b | 0.338 b |
| C-4(N) | - | 0.394 c | 0.403 b | 0.386 b | 0.337 b | 0.368 b | 0.331 b |
| N-0 | 0 | 0.373 e | 0.504 a | 0.457 a | 0.268 d | 0.359 b | 0.358 a |
| N-1 | 50 | 0.489 b | 0.561 a | 0.540 a | 0.373 b | 0.363 b | 0.430 a |
| N-2 | 100 | 0.475 c | 0.569 a | 0.498 a | 0.377 b | 0.451 a | 0.389 a |
| N-3 | 200 | 0.502 a | 0.508 a | 0.472 a | 0.407 a | 0.405 ab | 0.437 a |
| N-4 | 400 | 0.451 d | 0.502 a | 0.533 a | 0.330 c | 0.436 ab | 0.368 a |

C - Complementary nutrients - P, K, Ca and Mg

Table 10. - Average total sugar and amino nitrogen content of soybean leaves and stems (flowering stage) as affected by three levels of complementary nutrients associated with five levels of nitrogen.

| Treatment | | Total sugar and amino nitrogen in soybean tissue (per cent) | | | |
|---|---|---|---|---|---|
| | | Leaves | | Stems | |
| Nutrient Level Code | Rate Per Acre Pounds | Total Sugar | Amino Nitrogen | Total Sugar | Amino Nitrogen |
| C-0(N) | - | 2.44 c | 0.197 a | 1.04 c | 0.144 a |
| C-2(N) | - | 3.14 a | 0.146 b | 1.34 a | 0.120 b |
| C-4(N) | - | 2.65 b | 0.139 c | 1.18 b | 0.121 b |
| N-0 | 0 | 2.94 a | 0.117 d | 1.37 a | 0.076 d |
| N-1 | 50 | 2.79 b | 0.109 e | 1.28 b | 0.107 c |
| N-2 | 100 | 2.79 b | 0.205 a | 1.17 c | 0.137 b |
| N-3 | 200 | 2.54 c | 0.196 b | 1.21 c | 0.131 b |
| N-4 | 400 | 2.66 c | 0.179 c | 0.91 d | 0.190 a |

C - Complementary nutrients - P, K, Ca and Mg

## Soil Nutrient Levels, Crop Yields, and the Chemical Composition of Soybean Plants as Affected by Three Levels of Complementary Nutrients Associated with Five Levels of Phosphorus.

### Soil Nutrient Contents

The average effects of fertilizers upon soil test results are shown in Table 11. Increased rates of the complementary nutrients significantly increased the pH levels from 7.0 to 7.5. The soil test values for phosphorus were generally decreased while statistically significant increases in potassium, calcium, and magnesium levels were measured.

The use of different increments of phosphorus did not affect the pH levels. As would be expected, the soil test values for phosphorus were increased. The application of phosphate fertilizers did not significantly influence the soil test results for potassium. While statistically different values for calcium and magnesium were obtained, the differences do not suggest any trend so the variations were probably associated with naturally occurring differences in the soil.

### Crop Yields

The average weight of both stems and leaves as related to three levels of complementary nutrients and five levels of phosphorus are shown in Table 12. Only on the first sampling date were significant differences measured. Increasing levels of complementary nutrients decreased the weight of the stems and leaves at this time. On the last two sampling dates differences were measured but the differences were not statistically significant.

The use of phosphorus up to level P-3 generally increased the dry weight of leaves and stems on the first sampling date. Beyond this level the leaf weights decreased. No significant differences were measured on samples taken on August 3 or August 30.

Average soybean seed yields are shown in Table 13. The yields of seeds were increased by use of the complementary nutrients up to level C-2. At level C-4 the yields were similar to those obtained where only phosphorus was used.

The highest seed yields were obtained where 200 pounds per acre of phosphorus was used, P-3. Levels above or below resulted in lower yields but in some instances the differences were not statistically significant.

Chemical Composition

The nitrogen contents of the leaves and stems are shown in Table 14. The use of the complementary nutrients increased the per cent nitrogen in both parts on the first sampling date. These differences were not statistically significant on the second sampling date. However, by August 30 differences again were wide enough to be significant.

The use of phosphorus containing fertilizers increased the nitrogen levels in both the leaves and the stems on the first sampling date. The effect of different levels of phosphorus, however, was not consistent so far as the leaves are concerned. In the stems the highest nitrogen levels, 3.41 per cent, were measured at P-2 where 100 pounds of phosphorus was used. Where more than this rate was used the nitrogen content again decreased, dropping to 3.01 per cent.

No significant differences were measured at the second or third sampling dates in either the stems or the leaves. On all three dates the leaves contained almost twice as much phosphorus as did the stems.

The phosphorus contents of both the leaves and stems are shown in Table 15. The leaves contained more phosphorus than the stems. In both the leaves and stems the phosphorus levels were decreased where increasing levels of the complementary nutrients were used. On the last two sampling dates differences were not as great and were therefore less significant.

The higher levels of application of phosphorus on the average resulted in an increase in the phosphorus content of both the leaves and the stems on all three sampling dates. This effect, however, was not as noticeable nor as significant on the last date, August 30.

The average potassium content of leaves and stems is shown in Table 16. The levels of potassium in the stems, especially on the last two sampling dates, were generally higher than in the leaves. The use of the complementary nutrients in each case significantly increased the potassium levels. The second level of complementary ions did not, however, cause a further increase in the potassium content of leaves on the last two sampling dates. In the stems the differences resulting from variable rates of complementary ions were significant on all three dates.

The use of phosphorus had a tendency to decrease the potassium content of both the leaves and the stems on all three sampling dates although the differences were neither consistent nor great. On every date the use of 400 pounds of phosphorus per acre, P-4, resulted in a significant decrease in the potassium content of both the leaves and stems.

The average effect of using the complementary nutrients and the five levels of phosphorus upon the calcium content of soybean leaves and stems is shown in Table 17. On the first sampling date the calcium content of the leaves was lower than in the stems. On the second and third dates the levels were reversed.

In the leaves, on all three dates, the use of the complementary nutrients decreased the calcium contents. There was no further decrease however as a result of increasing the rate of application of the complementary nutrients. In the stems, differences were very small, but some were statistically significant. This was also the case in regard to the average effect of various levels of applied phosphorus upon the calcium content of the leaves and stems.

The average magnesium percentages in soybean leaves and stems are shown in Table 18. They were highest in the leaves in every instance. The levels in the leaves were generally highest at the time of the second sampling during blossom. This trend was not as evident in the stems. Statistically significant reductions resulted from the effect of complementary nutrients at the time of the first sampling. The magnesium levels were lowest where the C-4 level of complementary nutrients were used except in the case of stems at the July 12 sampling.

The use of complementary nutrients resulted in a decreased magnesium content of the leaves on all three sampling dates, although the differences resulting from the C-4 over the C-2 levels were not significant on August 3. A similar situation was noticed in the stems.

The use of phosphorus resulted in a general increase in magnesium levels in both the leaves and stems although the differences found in the stems caused by various rates of phosphorus were insignificant on the last sampling date at pod-forming time.

The effect of phosphorus upon the total sugar and amino nitrogen content of leaves and stems is shown in Table 19. The sugar content of the leaves was more than that measured in the stems and the use of the C-2 level of complementary nutrients increased the sugar content of the leaves. An increase to the C-4 level however, caused a decrease in sugar to approximately the same level as was measured where only phosphorus was used. In the stems the use of complementary nutrients at both levels definitely resulted in decreases in sugar levels. The use of phosphorus up to rates of 100 pounds per acre, P-2, resulted in an increase in sugar levels in the leaves while in the stems the maximum sugar content was obtained where 200 pounds per acre, P-3, of phosphorus had been used.

The use of phosphorus had a general tendency to increase the percentages of amino nitrogen in both the leaves and the stems.

Discussion

As might be expected, the use of phosphate fertilizers increased the soil test values for phosphorus. The increase, however, was not proportional to the amount of fertilizer used. Undoubtedly considerable fixation of phosphorus by the soil occurred. Chemical precipitation with calcium and magnesium introduced through the use of lime attributed to the decrease in soil test values.

The highest yield of seed was obtained where phosphorus was applied at the rate of 200 pounds per acre. At this level soil test results were equivalent to 72 pounds per acre, which is considered to be in the "high" range for soybeans.

The levels of phosphorus in the leaves and stems, within the range that fertilizer increased yields, did not vary greatly. Beeson (9) commented that "the absolute change in phosphorus content of the plant is small, generally much less than 10 per cent." Cook et al. (20) explains this by stating that the plant or plant part merely makes the amount of growth which the nutrient supply permits, keeping the chemical content of the plant tissue almost constant.

The use of phosphorus increased the calcium and magnesium contents in soybean plants as is shown in figure 1. This was associated with a general decrease in potassium levels. Pretty (76) suggested that the inclusion of phosphorus resulted in more vigorous root growth, thus increasing cation accumulation. Hoagland et al. (44) indicated that the use of anions tended to increase the uptake of cations. In this research this occurred with calcium and magnesium but not with potassium. Others (62 and 63) have hypothesized cation uptake is related to base saturation. These data, however, do not suggest this relationship. Differences observed in the accumulation of cation have been attributed to the morphology and physiology of the roots of this plant. Drake et al. (21) observed that the ability of plants to take up cations was largely controlled by the cation exchange capacity of the plant root and the valence of the cation. At low concentrations, divalent cations were absorbed relatively in greater amounts than monovalent ions from the soil colloid, the greater the cation exchange capacity of the plant root colloid. They also observed that soybean roots had the greatest cation exchange capacity. These would probably explain in the increase accumulation of divalent cations. The sum of the cations tends to be a constant, hence, if larger amounts of calcium and magnesium are absorbed by the root, the lower would be the content of potassium.

The application of phosphorus, on the average, increased the sugar and the alpha amino nitrogen content of the soybean plant. With the identification of ribulose diphosphate (7) the role of phosphorus in photosynthesis has been stressed. Arnon (5) stated, "The intimate association of phosphate with photosynthesis necessitates a realignment of traditional concepts of plant nutrition. It has been often assumed in the past that carbon dioxide assimilation in photosynthesis proceeds by an autonomous path without a direct participation of the inorganic elements absorbed by the roots from the soil. The term mineral nutrition has been used to describe the events associated with absorption and utilization of inorganic elements derived from the root environment. It appears, however, that mineral nutrition and photosynthesis can no longer be treated separately. In the early events of photosynthesis phosphate assimilation cannot be separated from carbon assimilation. There is little doubt that as our knowledge of photosynthesis advances, other intimate relations between inorganic elements derived from the root environment and assimilation of carbon, will come to light."

The formation of sugars such as hexoses and sucroses in photosynthesis aided by phosphate has been explained in the works of Benson and Calvin (8). Again, participation of inorganic phosphate in the conversion of starch to sugar has

been recognized by Hassid (43). In addition, phosphorus takes part in the phosphorylation reactions leading to pyruvic acid which is a starting material for the Krebs-cycle Alpha ketoglutaric acid, a building material in the synthesis of amino acid is a product of the Krebs-cycle. Well-defined mechanisms could not be made as innumerable reactions taking place in a plant are still unknown.

In this research, the use of phosphorus tended to decrease the levels of potassium in the plant when at the flowering stage. According to Nightingale et al. (68) and others (95, 16) potassium is essential for the synthesis of proteins from amino acids. Therefore this helps to explain the accumulation of amino nitrogen that occurred at this stage of development.

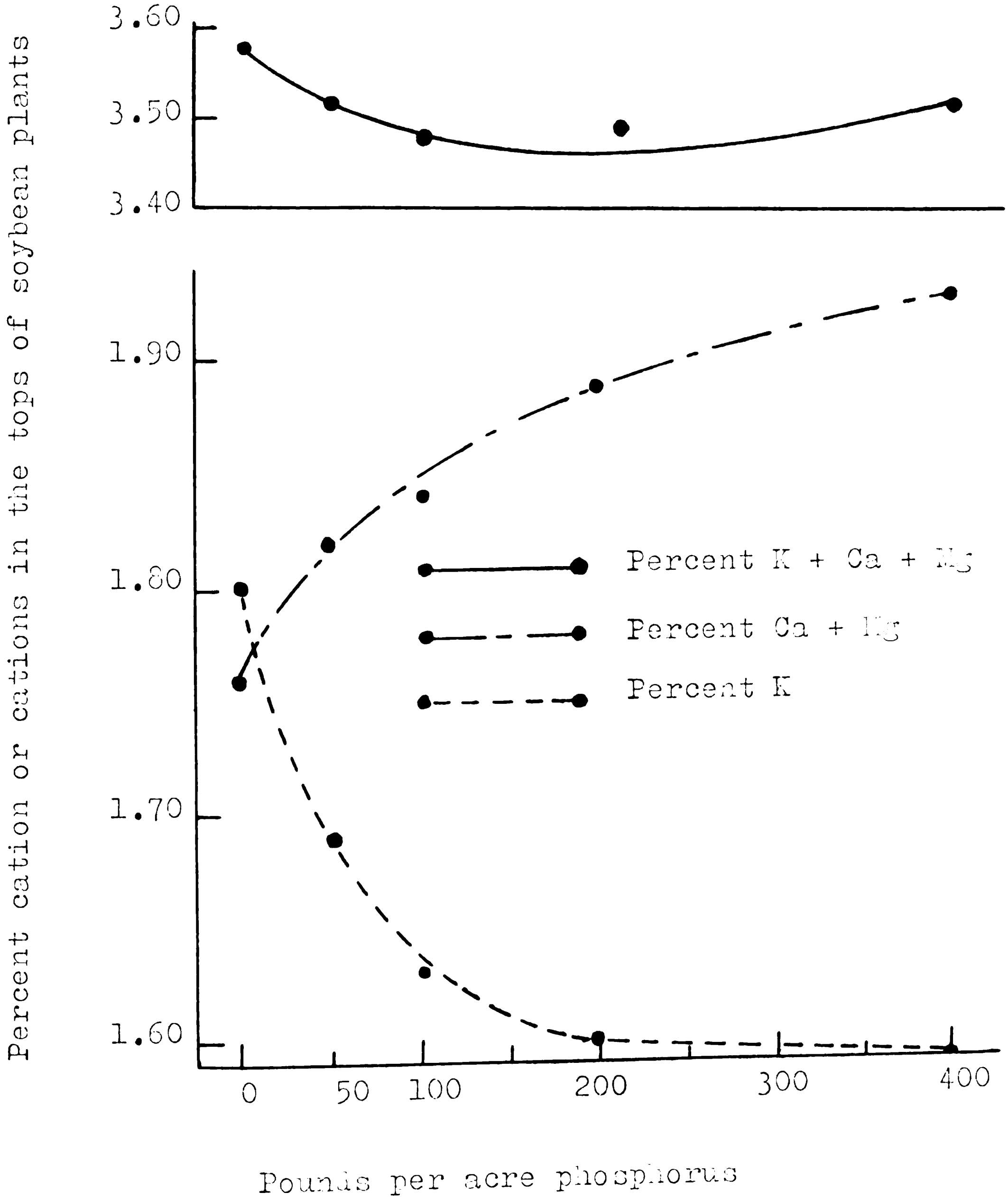


Figure 1. Cation content of soybean tops (leaves and stems) as affected by applications of phosphorus fertilizers.

Table 11. – Average soil test results as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Soil Reaction | Available soil nutrients, Pounds per Acre: Phosphorus | Potassium | Calcium | Magnesium |
|---|---|---|---|---|---|---|
| C-0(P) | - | 7.0 c | 72 a | 87 c | 3057 c | 810 c |
| C-2(P) | - | 7.3 b | 67 a | 130 b | 3830 b | 938 b |
| C-4(P) | - | 7.5 a | 45 b | 363 a | 5143 a | 1192 a |
| P-0 | 0 | 7.3 a | 31 d | 192 a | 4017 ab | 1080 a |
| P-1 | 50 | 7.3 a | 40 cd | 186 a | 3856 b | 917 c |
| P-2 | 100 | 7.2 a | 51 c | 229 a | 4250 a | 1003 b |
| P-3 | 200 | 7.4 a | 72 b | 182 a | 3944 ab | 1014 b |
| P-4 | 400 | 7.2 a | 112 a | 181 a | 3983 ab | 886 c |

C - Complementary nutrients N, K, Ca and Mg

Table 12. - Average leaf and stem yields of soybeans at three stages of development as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Dry Weight of 10 Plants (gms) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(P) | - | 2.17 a | 12.8 a | 67.4 a | 0.87 b | 7.3 a | 65.0 a |
| C-2(P) | - | 2.00 b | 13.0 a | 70.9 a | 0.89 a | 7.9 a | 66.4 a |
| C-4(P) | - | 1.78 c | 13.0 a | 76.5 a | 0.75 c | 7.1 a | 66.1 a |
| P-0 | 0 | 1.77 d | 12.1 a | 59.7 a | 0.71 d | 7.1 a | 54.0 a |
| P-1 | 50 | 1.92 c | 12.4 a | 72.4 a | 0.83 b | 6.5 a | 64.8 a |
| P-2 | 100 | 1.97 b | 14.0 a | 79.2 a | 0.83 b | 7.9 a | 72.5 a |
| P-3 | 200 | 2.22 a | 13.7 a | 76.5 a | 1.00 a | 8.5 a | 75.0 a |
| P-4 | 400 | 1.99 b | 12.3 a | 70.3 a | 0.81 c | 6.9 a | 62.7 a |

C - Complementary nutrients N, K, Ca and Mg

Table 13. - Average soybean seed yields as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Yield Per Acre (Bushels) |
|---|---|---|
| C-0(P) | - | 23.7 b |
| C-2(P) | - | 26.3 a |
| C-4(P) | - | 23.8 b |
| P-0 | 0 | 23.3 c |
| P-1 | 50 | 24.2 bc |
| P-2 | 100 | 25.7 ab |
| P-3 | 200 | 27.6 a |
| P-4 | 400 | 22.3 c |

C - Complementary nutrients N, K, Ca and Mg

Table 14. - Average nitrogen content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Leaves: July 12 | Leaves: August 3 | Leaves: August 30 | Stems: July 12 | Stems: August 3 | Stems: August 30 |
|---|---|---|---|---|---|---|---|
| C-0(P) | - | 5.03 c | 5.23 a | 4.62 b | 2.83 c | 2.59 a | 1.93 c |
| C-2(P) | - | 5.31 a | 5.36 a | 4.83 b | 3.31 b | 2.54 a | 2.27 b |
| C-4(P) | - | 5.14 b | 5.42 a | 5.15 a | 3.44 a | 2.67 a | 2.65 a |
| P-0 | 0 | 5.04 d | 5.47 a | 5.04 a | 3.10 c | 2.66 a | 2.42 a |
| P-1 | 50 | 5.21 b | 5.37 a | 4.87 a | 3.32 b | 2.57 a | 2.26 a |
| P-2 | 100 | 5.16 bc | 5.36 a | 4.78 a | 3.41 a | 2.70 a | 2.24 a |
| P-3 | 200 | 5.09 cd | 5.33 a | 4.79 a | 3.14 c | 2.47 a | 2.17 a |
| P-4 | 400 | 5.29 a | 5.16 a | 4.84 a | 3.01 d | 2.61 a | 2.32 a |

Nitrogen in Soybean Tissue (per cent)

C - Complementary nutrients N, K, Ca and Mg

Table 15. - Average phosphorus content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Phosphorus in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(P) | - | 0.381 a | 0.513 a | 0.324 a | 0.306 a | 0.291 a | 0.230 a |
| C-2(P) | - | 0.285 b | 0.404 b | 0.312 a | 0.200 b | 0.236 b | 0.208 ab |
| C-4(P) | - | 0.257 c | 0.396 b | 0.282 b | 0.192 c | 0.225 b | 0.188 b |
| P-0 | 0 | 0.261 d | 0.365 c | 0.279 b | 0.196 c | 0.193 d | 0.171 c |
| P-1 | 50 | 0.246 d | 0.373 c | 0.287 b | 0.196 c | 0.217 cd | 0.190 bc |
| P-2 | 100 | 0.280 c | 0.449 b | 0.281 b | 0.225 b | 0.253 bc | 0.204 bc |
| P-3 | 200 | 0.347 b | 0.456 b | 0.278 b | 0.181 d | 0.300 a | 0.222 ab |
| P-4 | 400 | 0.405 a | 0.546 a | 0.405 a | 0.364 a | 0.290 ab | 0.255 a |

C - Complementary nutrients N, K, Ca and Mg

Table 16. - Average potassium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Potassium in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(P) | - | 1.62 c | 1.31 b | 1.09 b | 1.55 c | 1.89 c | 1.15 c |
| C-2(P) | - | 2.38 b | 1.91 a | 1.62 a | 2.84 b | 3.35 b | 2.10 b |
| C-4(P) | - | 2.48 a | 1.94 a | 1.72 a | 3.37 a | 3.90 a | 2.43 a |
| P-0 | 0 | 2.38 a | 1.82 a | 1.59 a | 2.89 a | 3.25 a | 2.11 a |
| P-1 | 50 | 2.02 d | 1.69 ab | 1.50 ab | 2.36 e | 3.05 ab | 1.92 ab |
| P-2 | 100 | 2.10 c | 1.74 ab | 1.45 ab | 2.50 d | 3.07 ab | 1.84 ab |
| P-3 | 200 | 2.15 b | 1.75 ab | 1.45 ab | 2.61 b | 3.01 ab | 1.75 b |
| P-4 | 400 | 2.13 bc | 1.60 b | 1.39 b | 2.57 c | 2.86 b | 1.83 b |

C - Complementary nutrientsN, K, Ca and Mg

Table 17. - Average calcium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment | | Calcium in Soybean Tissue (per cent) | | | | | |
|---|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Leaves | | | Stems | | |
| | | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(P) | - | 1.49 a | 1.72 a | 1.91 a | 1.55 b | 1.53 a | 0.95 b |
| C-2(P) | - | 1.35 b | 1.63 b | 1.69 b | 1.55 b | 1.54 a | 1.05 a |
| C-4(P) | - | 1.35 b | 1.63 b | 1.66 b | 1.58 a | 1.62 a | 1.07 a |
| P-0 | 0 | 1.38 b | 1.63 b | 1.60 b | 1.54 b | 1.60 a | 1.05 a |
| P-1 | 50 | 1.39 b | 1.60 b | 1.76 a | 1.53 b | 1.54 a | 1.01 a |
| P-2 | 100 | 1.40 ab | 1.68 ab | 1.76 a | 1.59 a | 1.58 a | 1.03 a |
| P-3 | 200 | 1.42 a | 1.76 a | 1.79 a | 1.61 a | 1.53 a | 1.00 a |
| P-4 | 400 | 1.40 ab | 1.74 a | 1.84 a | 1.55 b | 1.56 a | 1.01 a |

C - Complementary nutrients N, K, Ca and Mg

Table 18. - Average magnesium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment Nutrient Level Code | Treatment Rate Per Acre (Pounds) | Magnesium in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(P) | - | 0.581 a | 0.840 a | 0.606 a | 0.338 a | 0.605 a | 0.531 a |
| C-2(P) | - | 0.435 b | 0.460 b | 0.453 b | 0.296 c | 0.375 b | 0.392 b |
| C-4(P) | - | 0.402 c | 0.444 b | 0.390 c | 0.308 b | 0.348 b | 0.303 c |
| P-0 | 0 | 0.432 c | 0.482 b | 0.464 bc | 0.230 e | 0.373 c | 0.386 a |
| P-1 | 50 | 0.482 ab | 0.546 ab | 0.429 c | 0.317 d | 0.408 bc | 0.416 a |
| P-2 | 100 | 0.477 b | 0.607 a | 0.428 c | 0.324 c | 0.431 abc | 0.416 a |
| P-3 | 200 | 0.486 a | 0.608 a | 0.527 ab | 0.338 b | 0.488 ab | 0.446 a |
| P-4 | 400 | 0.485 a | 0.564 ab | 0.568 a | 0.363 a | 0.513 a | 0.380 a |

C - Complementary nutrients N, K, Ca and Mg

Table 19. - Average total sugar and amino nitrogen content of soybean leaves and stems (flowering stage) as affected by three levels of complementary nutrients associated with five levels of phosphorus.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Leaves: Total Sugar | Leaves: Amino Nitrogen | Stems: Total Sugar | Stems: Amino Nitrogen |
|---|---|---|---|---|---|
| | | Total sugar and amino nitrogen in soybean tissue (per cent) | | | |
| C-0(P) | - | 3.01 b | 0.131 b | 2.00 a | 0.121 c |
| C-2(P) | - | 3.33 a | 0.163 a | 1.36 b | 0.135 b |
| C-4(P) | - | 3.05 b | 0.165 a | 1.26 c | 0.146 a |
| P-0 | 0 | 2.70 d | 0.131 c | 1.34 d | 0.099 d |
| P-1 | 50 | 3.05 c | 0.139 b | 1.46 c | 0.100 d |
| P-2 | 100 | 3.42 a | 0.160 a | 1.69 b | 0.126 c |
| P-3 | 200 | 3.26 b | 0.126 c | 1.77 a | 0.133 b |
| P-4 | 400 | 3.23 b | 0.165 a | 1.44 c | 0.179 a |

C - Complementary nutrients - P, K, Ca and Mg

## Soil Nutrient Levels, Crop Yields, and the Chemical Composition of Soybean Plants as Affected by Three Levels of Complementary Nutrients Associated with Five Levels of Potassium.

### Soil Nutrient Contents

The average effects of potassium on soil test results, are shown in Table 20. The use of complementary nutrients increased the pH and the available phosphorus, calcium, and magnesium levels in the soil. The application of potassium alone and at different rates had no effect upon pH or the available calcium levels in the soil but such treatment did decrease soil test values for phosphorus and magnesium and increase the levels of available potassium threefold.

### Crop Yields

The use of complementary nutrients, as associated with potassium increased on the first sampling date only, the dry weight of both leaves and stems. (Table 21) Various levels of potassium fertilizer applied to the soil also affected the dry weight of leaves and stems on the first sampling date but not in a consistent manner.

The effects of these treatments upon soybean seed yields are shown in Table 22. The use of complementary nutrients increased the seed yield approximately five bushels per acre. Potassium had the general effect of decreasing yields when this element was used at the K-4 level, 1200 pounds per acre.

Chemical Composition

The nitrogen levels in the leaves and stems are shown in Table 23. Again, the leaves contained approximately two times the amount of nitrogen that was found in the stems. The use of complementary nutrients generally increased the nitrogen content of both the leaves and the stems. The differences in the leaves on the second sampling date were not statistically significant.

The use of potassium applied at different rates, on the average, resulted in a lower level of this element in both the stems and leaves. Statistically significant differences were obtained on each sampling date except the second. In this instance the trend was present but the differences were not statistically significant.

The effect on phosphorus levels in the plants is shown in Table 24. The use of complementary nutrients had the general effect of increasing phosphorus in both the stems and leaves. On the first sampling date the levels at C-4 were lower than at C-2. By pod-filling time the plants grown on plots receiving the C-4 levels contained more phosphorus than the plants on the C-2 plots.

The use of potassium at different levels generally decreased phosphorus in the plants on the first sampling date. By pod-filling time such differences were not significant.

In both the stems and leaves on the first sampling date, the potassium levels were decreased by the use of complementary nutrients. (Table 25) Such differences became

insignificant by pod-filling time. The use of potassium increased the potassium levels in both the stems and leaves on all of the three sampling dates and increasing rates generally resulted in further increases.

Calcium levels in the leaves were increased as a result of using complementary nutrients. (Table 26) Differences, however, were not significant at pod-filling time. In the stems, significant differences were measured but the differences were actually very small. This was also the situation in regard to the effect of potassium upon the percentage of calcium in the plants both leaves and stems.

The use of complementary nutrients increased magnesium levels in both leaves and stems on all three sampling dates. (Table 27) On all dates, the levels were highest in the leaves at the C-4 treatment level. In the stems, on the last sampling date, differences resulting from the C-2 and C-4 treatments were not statistically significant. The plants from the plots which received the K-4 level, 1200 pounds of potassium per acre, were as low or lower in magnesium in both the stems and the leaves on all sampling dates than were the plants from plots that received less potassium.

The use of complementary nutrients resulted in a decrease in total sugars in both the leaves and the stems. (Table 28) The use of potassium increased the quantity of total sugars in the leaf. Beyond the K-2 level the quantity of sugar decreased. In the stems the maximum sugar content was also measured at level K-2 where 300 pounds of potassium per acre had been used.

The amino nitrogen levels were increased in both the leaves and the stems by the use of complementary nutrients. The use of potassium generally decreased the amino nitrogen levels in both the leaves and the stems except in one instance, the K-2 level where 300 pounds of potassium per acre was used.

Discussion

The lack of a seed yield response to potassium in this experiment was probably due to the fact that the soil initally contained a rather high level of potassium. Lawton and Cook (51) stated, "Good acre yields of alfalfa and sweet clover require from 100 to 130 pounds of potassium, whereas for red clover, crimson clover, soybeans, cowpeas and vetch, the profitable requirement is 50 to 75 pounds." Nelson (66) reported that the use of potassium increased soybeans yields where the soil contained 25 pounds of exchangeable potassium per acre. The soil in this experiment on the average, contained 100 pounds of exchangeable potassium. The use of potassium at 1200 pounds per acre caused a decrease in the uptake of magnesium and nitrogen. This possibly explains the decrease in seed yields at this level.

The effect of potassium fertilizers upon the levels in the leaves and stems are in agreement with other work. Lawton and Cook (51), in a comprehensive review of literature, pointed out that the potassium content of the crop is

generally increased as the level of exchangeable potassium in the soil is increased by the use of fertilizers provided the level of soil potassium initially present is not extremely high.

In this study the use of potassium decreased the nitrogen content of the leaves and stems. A number of workers have suggested that there is a close relationship between soil fertility and nitrogen fixation. Albrecht (1) suggested that the absorption of larger amounts of potassium in relation to the quantity of calcium in the early vegetative growth may reduce the nitrogen fixation rate. Potassium may replace calcium to the extent that the wider potassium to calcium ratio results in a reduction of the nitrogen fixing ability of the plant. Hampton and Albrecht (35), in a study involving a clay culture, observed that a low ratio of potassium to calcium was necessary for maximum nitrogen fixation. Heavy applications of potassium chloride probably retarded nodule formation, thus decreasing the amount of nitrogen fixed.

The data indicated that the application of potassium significantly reduced the uptake of magnesium. Magnesium deficiency symptoms were observed on the plots that received only potassium at the rates of either 600 or 1200 pounds per acre.

Several investigators have suggested that magnesium deficiency develops not only at low levels of exchangeable magnesium, but also that it may be induced by the use of high rates of potassoum on medium or high magnesium soils. This relationship was observed by Southwick (85) and Wehunt and Purvis (101) in apple orchards, Boyton and Burrel (11) in apple trees, and Walsh and O'Donahoe (97) in potatoes.

Nelson et al. (66), in North Carolina, studied the relationship of foliar deficiency symptoms in soybeans to magnesium levels in the leaflets and the petioles. The leaflets and petioles from magnesium deficient plants contained 0.13 and 0.18 per cents magnesium, respectively. The data obtained in this investigation showed that foliar deficiency symptoms were associated with magnesium concentrations in the leaves of 0.295 per cent or less. The reason for the higher concentration than was found by Nelson et al., is probably due to the difference in soil, climate, and soybean variety. In addition, all of the leaves of the plants were used in this evaluation. Webb et al. (99) working with all of the leaves from flowering plants that were just starting to show symptoms of magnesium deficiency, suggested that the deficiency occurred when the leaves contained less than 0.24 per cent magnesium. Carolus (17), in explaining the cause of magnesium deficiency, reasoned that the deficiency was not always associated with a low magnesium concentration in the plant but may be the result of unproportional absorption of cations and that magnesium deficiency could occur when a high potassium plus calcium to magnesium ratio existed in the soil. Walsh and Clark (98) felt that the potassium to magnesium ratio in the soil determined the degree of magne-

sium uptake by tomatoes. If the potassium to magnesium ratio was significantly high, chlorosis developed even when the nutrient medium had a relatively high level of available magnesium.

Lundegardh (54) explained the antagonistic phenomenon of potassium as related to magnesium absorption as follows: Potassium in high amounts exerts a degenerative influence on the protoplasmic membrane of the roots by decreasing the negative potential to below a minus 50 m.v. This causes the protoplasm to be more liquid as a result of the hydration. Also, the hydrogen ion concentration of the surface layer is decreased. Magnesium acts in the opposite way by attracting water molecules from the surrounding membrane area, thus dehydrating the membrane. This process increases the density, surface tension, and stability of the membrane, as well as its tolerance to a higher electrostatic charge.

The data in this investigation support the views of Carolus (17) and Walsh and Clark (98), and are consistent with the views of Lundegardh.

With lower rates of application, the total sugar content of the soybean plants increased, while at higher rates there was a decrease. Several investigators (2, 24, 47, 83 and 96) have observed similar results in different crops.

Nightingale (68) found that potassium was essential for carbon dioxide assimilation. Sideris et al. (83), observed that total sugar values were greater in low than in high potassium plants. They concluded that a low rate of polymerization of sugars to starches or other complex carbohydrates occurred in plants containing a low level of potassium. The data obtained in this investigation are consistent with this view.

Plant physiologists and agronomists (16, 19, 38, and 68) have each reported that potassium plays an essential role in the synthesis of protein from amino nitrogen. The data presented here support these views.

Table 20. - Average soil test results as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment | | Available soil nutrients | | | | |
|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Soil Reaction | Phosphorus | Pounds Per Acre Potassium | Calcium | Magnesium |
| C-0(K) | - | 7.1 b | 30 c | 161 a | 2779 c | 823 c |
| C-2(K) | - | 7.4 a | 56 b | 155 a | 3797 b | 936 b |
| C-4(K) | - | 7.5 a | 100 a | 171 a | 4997 a | 1195 a |
| K-0 | 0 | 7.3 a | 72 a | 85 c | 3872 a | 1060 a |
| K-1 | 150 | 7.4 a | 65 ab | 97 c | 3867 a | 1056 a |
| K-2 | 300 | 7.3 a | 61 ab | 131 c | 3799 a | 920 c |
| K-3 | 600 | 7.3 a | 54 b | 191 b | 3789 a | 987 b |
| K-4 | 1200 | 7.2 a | 57 b | 307 a | 3961 a | 901 c |

C - Complementary nutrients - N, P, Ca and Mg

Table 21. - Average leaf and stem yields of soybeans at three stages of development as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Dry Weight of 10 Plants (gms) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(K) | - | 1.82 c | 10.3 a | 53.6 a | 0.84 c | 6.0 a | 54.4 a |
| C-2(K) | - | 2.00 b | 13.6 a | 69.7 a | 0.89 a | 8.1 a | 66.4 a |
| C-4(K) | - | 2.12 a | 12.5 a | 78.7 a | 0.87 b | 7.1 a | 68.6 a |
| K-0 | 0 | 2.01 b | 13.9 a | 70.9 a | 0.90 b | 7.9 a | 64.4 a |
| K-1 | 150 | 1.95 c | 12.0 a | 65.0 a | 0.79 e | 7.2 a | 60.8 a |
| K-2 | 300 | 1.89 d | 11.5 a | 74.4 a | 0.88 c | 6.7 a | 71.6 a |
| K-3 | 600 | 2.19 a | 12.5 a | 66.2 a | 0.95 a | 7.6 a | 64.3 a |
| K-4 | 1200 | 1.85 e | 10.8 a | 60.2 a | 0.81 d | 6.1 a | 54.9 a |

C - Complementary nutrients N, P, Ca and Mg

Table 22. - Average soybean seed yields as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Yield Per Acre (Bushels) |
|---|---|---|
| C-0(K) | - | 21.4 b |
| C-2(K) | - | 26.9 a |
| C-4(K) | - | 26.1 a |
| K-0 | 0 | 25.0 a |
| K-1 | 150 | 27.0 a |
| K-2 | 300 | 26.2 a |
| K-3 | 600 | 25.5 a |
| K-4 | 1200 | 20.2 b |

C - Complementary nutrients - N, P, Ca and Mg

Table 23. - Average nitrogen content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment | | Nitrogen in Soybean Tissue (per cent) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Leaves | | | Stems | | |
| Nutrient Level Code | Rate Per Acre (Pounds) | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(K) | - | 4.46 b | 5.13 a | 4.41 c | 2.19 c | 2.25 c | 1.72 c |
| C-2(K) | - | 5.16 a | 5.32 a | 4.73 b | 3.44 b | 2.66 b | 2.08 b |
| C-4(K) | - | 5.15 a | 5.36 a | 5.08 a | 3.61 a | 2.92 a | 3.00 a |
| K-0 | 0 | 5.18 a | 5.33 a | 4.83 a | 3.34 a | 3.03 a | 2.48 a |
| K-1 | 150 | 4.99 b | 5.31 a | 4.90 a | 3.11 c | 2.58 b | 2.32 ab |
| K-2 | 300 | 4.76 c | 5.31 a | 4.73 ab | 3.22 b | 2.58 b | 2.19 bc |
| K-3 | 600 | 4.70 c | 5.20 a | 4.68 ab | 2.90 d | 2.47 b | 2.27 bc |
| K-4 | 1200 | 4.99 b | 5.20 a | 4.56 b | 2.82 e | 2.38 b | 2.06 c |

C - Complementary nutrients N, P, Ca and Mg

Table 24. - Average phosphorus content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Leaves: July 12 | Leaves: August 3 | Leaves: August 30 | Stems: July 12 | Stems: August 3 | Stems: August 30 |
|---|---|---|---|---|---|---|---|
| C-0(K) | - | 0.255 b | 0.400 b | 0.257 b | 0.185 b | 0.215 a | 0.165 b |
| C-2(K) | - | 0.269 a | 0.450 a | 0.292 b | 0.212 a | 0.227 a | 0.210 a |
| C-4(K) | - | 0.260 b | 0.435 a | 0.345 a | 0.191 b | 0.244 a | 0.226 a |
| K-0 | 0 | 0.320 a | 0.434 ab | 0.310 a | 0.214 a | 0.250 a | 0.205 a |
| K-1 | 150 | 0.259 c | 0.411 b | 0.277 a | 0.179 d | 0.212 a | 0.198 a |
| K-2 | 300 | 0.276 b | 0.466 a | 0.304 a | 0.202 b | 0.237 a | 0.189 a |
| K-3 | 600 | 0.214 e | 0.408 b | 0.289 a | 0.188 c | 0.213 a | 0.210 a |
| K-4 | 1200 | 0.238 d | 0.423 b | 0.311 a | 0.198 b | 0.232 a | 0.199 a |

Phosphorus in Soybean Tissue (per cent)

C - Complementary nutrients N, P, Ca and Mg

Table 25. - Average potassium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Leaves: July 12 | Leaves: August 3 | Leaves: August 30 | Stems: July 12 | Stems: August 3 | Stems: August 30 |
|---|---|---|---|---|---|---|---|
| C-0(K) | - | 2.36 a | 1.82 a | 1.52 a | 2.83 a | 3.28 a | 1.89 a |
| C-2(K) | - | 2.12 b | 1.77 a | 1.46 a | 2.51 b | 3.13 ab | 1.79 a |
| C-4(K) | - | 2.03 c | 1.60 b | 1.47 a | 2.31 c | 2.92 b | 1.83 a |
| K-0 | 0 | 1.67 d | 1.30 d | 1.09 d | 1.47 e | 1.90 d | 1.10 d |
| K-1 | 150 | 1.97 c | 1.64 c | 1.42 c | 1.97 d | 2.69 c | 1.55 c |
| K-2 | 300 | 2.22 b | 1.81 b | 1.57 b | 2.55 c | 3.18 b | 1.93 b |
| K-3 | 600 | 2.52 a | 1.91 ab | 1.65 ab | 3.25 b | 3.78 a | 2.10 b |
| K-4 | 1200 | 2.48 a | 2.00 a | 1.69 a | 3.52 a | 3.99 a | 2.51 a |

Potassium in Soybean Tissue (per cent)

C - Complementary nutrients N, P, Ca and Mg

Table 26. - Average calcium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Calcium in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(K) | - | 1.32 c | 1.59 b | 1.75 a | 1.54 b | 1.67 a | 0.89 b |
| C-2(K) | - | 1.39 b | 1.67 a | 1.78 a | 1.67 a | 1.56 b | 1.03 a |
| C-4(K) | - | 1.48 a | 1.72 a | 1.81 a | 1.49 c | 1.62 ab | 0.98 ab |
| K-0 | 0 | 1.36 cd | 1.70 a | 1.81 a | 1.52 c | 1.52 c | 0.93 b |
| K-1 | 150 | 1.48 a | 1.67 a | 1.78 a | 1.51 c | 1.58 bc | 1.03 ab |
| K-2 | 300 | 1.35 d | 1.62 a | 1.75 a | 1.53 bc | 1.58 bc | 1.01 b |
| K-3 | 600 | 1.40 b | 1.64 a | 1.78 a | 1.55 b | 1.66 ab | 1.06 ab |
| K-4 | 1200 | 1.39 bc | 1.67 a | 1.78 a | 1.71 a | 1.73 a | 1.10 a |

C - Complementary nutrients N, P, Ca and Mg

Table 27. - Average magnesium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Magnesium in Soybean Tissue (per cent): Leaves, July 12 | Leaves, August 3 | Leaves, August 30 | Stems, July 12 | Stems, August 3 | Stems, August 30 |
|---|---|---|---|---|---|---|---|
| C-C(K) | - | 0.350 c | 0.412 c | 0.387 b | 0.263 c | 0.338 b | 0.318 b |
| C-2(K) | - | 0.476 b | 0.551 b | 0.445 b | 0.326 b | 0.333 b | 0.393 a |
| C-4(K) | - | 0.512 a | 0.615 a | 0.606 a | 0.403 a | 0.506 a | 0.420 a |
| K-0 | 0 | 0.581 a | 0.808 a | 0.740 a | 0.343 b | 0.544 a | 0.543 a |
| K-1 | 150 | 0.458 b | 0.499 b | 0.561 b | 0.305 c | 0.399 b | 0.389 b |
| K-2 | 300 | 0.428 c | 0.504 b | 0.440 c | 0.373 a | 0.449 b | 0.384 b |
| K-3 | 600 | 0.391 d | 0.484 b | 0.332 d | 0.340 b | 0.285 c | 0.304 bc |
| K-4 | 1200 | 0.373 e | 0.333 c | 0.324 d | 0.292 d | 0.285 c | 0.264 c |

C - Complementary nutrients N, P, Ca and Mg

Table 28. - Average total sugar and amino nitrogen content of soybean leaves and stems (flowering stage) as affected by three levels of complementary nutrients associated with five levels of potassium.

| Treatment | | Total sugar and amino nitrogen in soybean tissue (per cent) | | | |
|---|---|---|---|---|---|
| Nutrient | Rate | Leaves | | Stems | |
| Level Code | Per Acre (Pounds) | Total Sugar | Amino Nitrogen | Total Sugar | Amino Nitrogen |
| C-0(K) | - | 3.25 a | 0.099 c | 1.57 a | 0.066 c |
| C-2(K) | - | 3.17 b | 0.151 b | 1.45 b | 0.122 b |
| C-4(K) | - | 2.98 c | 0.214 a | 1.22 c | 0.184 a |
| K-0 | 0 | 3.01 c | 0.175 b | 1.52 b | 0.157 a |
| K-1 | 150 | 3.19 b | 0.134 d | 1.52 b | 0.101 d |
| K-2 | 300 | 3.58 a | 0.186 a | 1.62 a | 0.126 c |
| K-3 | 600 | 2.93 c | 0.137 cd | 1.15 d | 0.101 d |
| K-4 | 1200 | 2.95 c | 0.142 c | 1.25 c | 0.136 b |

C - Complementary nutrients - N, P, Ca and Mg

Soil Nutrient Levels, Crop Yields, and the Chemical Composition of Soybean Plants as Affected by Three Levels of Complementary Nutrients Associated with Five Levels of Calcium.

Soil Nutrient Contents

The average effects of fertilizers upon soil test results are shown in Table 29. The use of complementary nutrients reduced the pH level slightly. Soil test values for phosphorus, potassium and magnesium increased significantly, although the highest level of complementary nutrients was required to bring about a significantly increased potassium test. Soil test values for calcium were unaffected as a result of using the complementary nutrients.

The use of calcium up to Ca-3, 3200 pounds per acre, increased the pH level. This was associated with lower soil test values for phosphorus. Levels of potassium were unaffected but the test for calcium reflected the various quantities that had been added to the soil. The tests for magnesium varied greatly and were not closely related to the use of calcium.

Crop Yields

The use of complementary nutrients increased the yield of both the leaves and stems only on the first sampling date. (Table 30) This was also the situation in regard to the effect of the use of different rates of calcium. The use of up to 1600 pounds of calcium per acre, level Ca-2, increased the yield of leaves and stems. Beyond this level yields were reduced.

Seed yields are shown in Table 31. The use of complementary nutrients at level C-2 increased seed yields three bushels per acre, while at level C-4 the yields were reduced to a level below that which was obtained on the zero level of complementary nutrients. The use of the lowest level of calcium, 800 pounds per acre, Ca-1, resulted in a significantly increased seed yield. The use of more calcium than this did not further increase yields. In fact, yields were significantly reduced where the highest rate Ca-4 or 6400 pounds per acre, had been used.

Chemical Composition

The nitrogen content of the leaves was increased as a result of using the complementary nutrients only on the first sampling date. (Table 32) In the stems, an increase was measured on the first date. At this time rates had little effect upon the nitrogen content of the stems. On the third date the use of complementary nutrients at the C-2 level increased the nitrogen content of the stems. The increase, however, was not statistically significant. The use of the C-4 rate increased the nitrogen content significantly over that which was obtained where the second rate had been used.

The use of calcium likewise affected the nitrogen content of leaves and stems only on the first sampling date. In the stems the highest levels of nitrogen occurred where

3200 pounds of calcium per acre had been used, level Ca-3.

The phosphorus contents of leaves and stems as affected by complementary nutrients and calcium are shown in Table 33. In the leaves, the use of complementary nutrients at level C-2, on the first sampling date, significantly decreased the phosphorus level. On the later samplings the phosphorus content increased, although the difference was not statistically significant on the last date. The same occurred in the stems except the difference was significant on the third date and not significant on the second date.

The use of calcium generally decreased the phosphorus content of both the leaves and stems on the first sampling date. Statistically significant differences disappeared by the time of the third sampling.

The use of complementary nutrients resulted in a general increase in the potassium levels in both the stems and the leaves on all three sampling dates. (Table 34)

The use of calcium decreased the potassium content of leaves in samples taken on July 12 and August 3. The difference on the latter date, however, was not significant. In the stems a significant difference was obtained only on the first sampling date, July 12.

The use of complementary nutrients did not affect the calcium content of the stems. (Table 35) In the leaves the use of complementary nutrients reduced the calcium level on the first and third sampling date.

The effect of calcium upon the calcium content of leaves and stems was slight and not consistent. The calcium content of leaves generally increased during the season while the level in the stems was constant or reflected a decreased quantity. The level in the stems at pod-filling time was unusually constant and did not reflect any differences in calcium uptake.

The use of complementary nutrients decreased the magnesium level in the leaves. (Table 36) This also occurred in the stems except on the first sampling date.

The use of high rates of calcium had a tendency to reduce magnesium levels in both the stems and the leaves. Differences, while statistically significant, indirectly reflect original differences in the magnesium content of the soil and differences resulting from interactions involving other applied elements.

The use of complementary nutrients tended to reduce the total sugar level in both the leaves and the stems. (Table 37) The use of calcium up to rate Ca-2 increased the total sugar levels. In the stems the highest level was observed at Ca-1.

The use of complementary nutrients greatly increased the amino nitrogen content of the leaves. The increases were not as great in the stems.

The use of calcium increased amino nitrogen slightly in both the leaves and the stems. Variations, due to different rates of calcium, however, were such that they did not suggest any particular trend.

## Discussion

The use of calcium in combination with the complementary nutrients increased yield approximately three bushels per acre. This relatively small increase in yield was probably due to the fact that the soil naturally contained adequate quantities of calcium and had a rather satisfactory pH level. A review of literature suggests that a response to calcium might be expected only on relatively acid soils which contain low quantities of exchangeable calcium.

Table 29. - Average soil test results as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Soil Reaction | Available soil nutrients Pounds Per Acre Phosphorus | Potassium | Calcium | Magnesium |
|---|---|---|---|---|---|---|
| C-0(Ca) | - | 7.4 a | 32 c | 83 b | 3877 a | 829 c |
| C-2(Ca) | - | 7.3 ab | 58 b | 119 b | 3777 a | 888 b |
| C-4(Ca) | - | 7.2 b | 127 a | 397 a | 4083 a | 1127 a |
| Ca-0 | 0 | 7.0 d | 92 a | 209 a | 2917 e | 1030 a |
| Ca-1 | 800 | 7.2 c | 76 b | 195 a | 3428 d | 820 c |
| Ca-2 | 1600 | 7.3 bc | 70 b | 201 a | 3928 c | 929 b |
| Ca-3 | 3200 | 7.5 a | 67 bc | 224 a | 4350 b | 940 b |
| Ca-4 | 6400 | 7.4 ab | 55 c | 169 a | 4939 a | 1022 a |

C - Complementary nutrients - N, P, K and Mg

Table 30. - Average leaf and stem yields of soybeans at three stages of development as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Dry Weight of 10 Plants (gms) — Leaves: July 12 | Leaves: August 3 | Leaves: August 30 | Stems: July 12 | Stems: August 3 | Stems: August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Ca) | - | 2.02 c | 12.0 a | 67.1 a | 0.88 c | 6.8 a | 65.6 a |
| C-2(Ca) | - | 2.05 b | 13.5 a | 71.2 a | 0.91 b | 8.1 a | 69.4 a |
| C-4(Ca) | - | 2.07 a | 12.0 a | 80.3 a | 0.93 a | 6.9 a | 71.6 a |
| Ca-0 | 0 | 2.04 c | 12.3 a | 70.3 a | 0.90 c | 7.3 a | 67.1 a |
| Ca-1 | 800 | 2.13 b | 13.9 a | 76.7 a | 0.90 c | 8.4 a | 72.3 a |
| Ca-2 | 1600 | 2.19 a | 12.9 a | 75.4 a | 0.97 a | 7.4 a | 72.7 a |
| Ca-3 | 3200 | 1.96 d | 11.9 a | 72.8 a | 0.92 b | 7.0 a | 67.5 a |
| Ca-4 | 6400 | 1.91 e | 11.7 a | 69.1 a | 0.81 d | 6.3 a | 64.7 a |

C - Complementary nutrients - N, P, K and Mg

Table 31. - Average seed yields as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Yield Per Acre (Bushels) |
|---|---|---|
| C-0(Ca) | - | 24.0 b |
| C-2(Ca) | - | 27.2 a |
| C-4(Ca) | - | 23.6 b |
| Ca-0 | 0 | 23.8 bc |
| Ca-1 | 800 | 26.3 a |
| Ca-2 | 1600 | 26.1 ab |
| Ca-3 | 3200 | 25.4 ab |
| Ca-4 | 6400 | 23.0 c |

C - Complementary nutrients - N, P, K and Mg

Table 32. – Average nitrogen content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Nitrogen in Soybean Tissue (per cent): Leaves, July 12 | Leaves, August 3 | Leaves, August 30 | Stems, July 12 | Stems, August 3 | Stems, August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Ca) | - | 4.94 c | 5.35 a | 4.67 a | 3.00 b | 2.63 a | 1.92 b |
| C-2(Ca) | - | 5.06 b | 5.43 a | 4.89 a | 3.40 a | 2.71 a | 2.13 b |
| C-4(Ca) | - | 5.32 a | 5.36 a | 5.15 a | 3.36 a | 2.70 a | 2.78 a |
| Ca-0 | 0 | 5.28 a | 5.53 a | 4.95 a | 3.06 d | 2.76 a | 2.40 a |
| Ca-1 | 800 | 4.72 d | 5.30 a | 4.85 a | 3.01 e | 2.65 a | 2.30 a |
| Ca-2 | 1600 | 5.28 a | 5.37 a | 4.84 a | 3.35 b | 2.70 a | 2.14 a |
| Ca-3 | 3200 | 5.20 b | 5.32 a | 4.89 a | 3.56 a | 2.59 a | 2.27 a |
| Ca-4 | 6400 | 5.06 c | 5.39 a | 4.99 a | 3.29 c | 2.70 a | 2.26 a |

C - Complementary nutrients N, P, K and Mg

Table 33. - Average phosphorus content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment: Nutrient Level Code | Treatment: Rate Per Acre (Pounds) | Leaves: July 12 | Leaves: August 3 | Leaves: August 30 | Stems: July 12 | Stems: August 3 | Stems: August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Ca) | - | 0.284 c | 0.413 b | 0.281 a | 0.197 c | 0.227 a | 0.178 b |
| C-2(Ca) | - | 0.266 b | 0.456 a | 0.309 a | 0.185 b | 0.242 a | 0.212 a |
| C-4(Ca) | - | 0.301 a | 0.423 b | 0.319 a | 0.217 a | 0.245 a | 0.222 a |
| Ca-0 | 0 | 0.326 a | 0.437 ab | 0.325 a | 0.223 a | 0.244 a | 0.208 a |
| Ca-1 | 800 | 0.265 d | 0.445 ab | 0.305 a | 0.193 b | 0.243 a | 0.212 a |
| Ca-2 | 1600 | 0.282 c | 0.464 a | 0.288 a | 0.186 bc | 0.233 a | 0.201 a |
| Ca-3 | 3200 | 0.301 b | 0.417 c | 0.288 a | 0.217 a | 0.240 a | 0.205 a |
| Ca-4 | 6400 | 0.245 e | 0.393 c | 0.309 a | 0.179 c | 0.229 a | 0.193 a |

C - Complementary nutrients N, P, K and Mg

Table 34. – Average potassium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Ca) | - | 1.72 c | 1.33 b | 1.12 b | 1.68 c | 1.94 b | 1.19 c |
| C-2(Ca) | - | 2.30 b | 1.94 a | 1.60 a | 2.59 b | 3.58 a | 1.99 b |
| C-4(Ca) | - | 2.62 a | 1.96 a | 1.71 a | 3.58 a | 3.74 a | 2.41 a |
| Ca-0 | 0 | 2.45 a | 1.86 a | 1.50 a | 2.95 a | 3.24 a | 1.91 a |
| Ca-1 | 800 | 2.20 c | 1.77 ab | 1.52 a | 2.71 b | 3.17 a | 1.89 a |
| Ca-2 | 1600 | 2.00 d | 1.78 ab | 1.42 a | 2.36 d | 3.01 a | 1.79 a |
| Ca-3 | 3200 | 2.15 c | 1.64 b | 1.41 a | 2.53 c | 2.96 a | 1.77 a |
| Ca-4 | 6400 | 2.26 b | 1.68 b | 1.53 a | 2.53 c | 3.04 a | 1.96 a |

Potassium in Soybean Tissue (per cent)

C - Complementary nutrients N, P, K and Mg

Table 35. - Average calcium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Calcium in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Ca) | - | 1.51 a | 1.69 a | 1.87 a | 1.55 a | 1.60 a | 1.03 a |
| C-2(Ca) | - | 1.34 b | 1.65 a | 1.69 c | 1.57 a | 1.56 a | 1.01 a |
| C-4(Ca) | - | 1.38 b | 1.70 a | 1.78 b | 1.54 a | 1.58 a | 1.00 a |
| Ca-0 | 0 | 1.37 c | 1.65 a | 1.73 b | 1.48 d | 1.51 b | 0.99 a |
| Ca-1 | 800 | 1.35 c | 1.72 a | 1.80 ab | 1.56 c | 1.58 ab | 0.98 a |
| Ca-2 | 1600 | 1.54 a | 1.69 a | 1.82 ab | 1.61 b | 1.63 a | 0.99 a |
| Ca-3 | 3200 | 1.42 b | 1.67 a | 1.84 a | 1.46 d | 1.53 b | 0.98 a |
| Ca-4 | 6400 | 1.38 c | 1.67 a | 1.73 b | 1.68 a | 1.64 a | 1.03 a |

C - Complementary nutrients N, P, K and Mg

Table 36. - Average magnesium content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Ca) | - | 0.522 a | 0.694 a | 0.706 a | 0.307 c | 0.534 a | 0.530 a |
| C-2(Ca) | - | 0.433 c | 0.530 b | 0.411 b | 0.320 b | 0.344 c | 0.342 b |
| C-4(Ca) | - | 0.477 b | 0.410 c | 0.456 b | 0.371 a | 0.402 b | 0.332 b |
| Ca-0 | 0 | 0.487 c | 0.553 a | 0.548 ab | 0.327 c | 0.394 b | 0.412 a |
| Ca-1 | 800 | 0.508 b | 0.499 a | 0.492 bc | 0.363 a | 0.435 ab | 0.430 a |
| Ca-2 | 1600 | 0.519 a | 0.542 a | 0.551 ab | 0.350 b | 0.429 ab | 0.407 a |
| Ca-3 | 3200 | 0.451 d | 0.573 a | 0.594 a | 0.308 e | 0.384 b | 0.404 a |
| Ca-4 | 6400 | 0.423 e | 0.556 a | 0.436 c | 0.315 d | 0.492 a | 0.354 a |

Magnesium in Soybean Tissue (per cent)

C - Complementary nutrients N, P, K and Mg

Table 37. - Average total sugar and amino nitrogen content of soybean leaves and stems (flowering stage) as affected by three levels of complementary nutrients associated with five levels of calcium.

| Treatment Nutrient Level Code | Treatment Rate Per Acre (Pounds) | Leaves: Total Sugar | Leaves: Amino Nitrogen | Stems: Total Sugar | Stems: Amino Nitrogen |
|---|---|---|---|---|---|
| | | Total sugar and amino nitrogen in soybean tissue (per cent) | | | |
| C-0(Ca) | - | 3.29 a | 0.131 c | 1.66 a | 0.112 c |
| C-2(Ca) | - | 3.34 a | 0.173 b | 1.31 b | 0.134 b |
| C-4(Ca) | - | 2.89 b | 0.201 a | 1.09 c | 0.161 a |
| Ca-0 | 0 | 2.87 c | 0.160 c | 1.25 c | 0.121 c |
| Ca-1 | 800 | 3.16 b | 0.173 b | 1.51 a | 0.160 a |
| Ca-2 | 1600 | 3.36 a | 0.175 ab | 1.37 b | 0.132 b |
| Ca-3 | 3200 | 3.23 b | 0.179 a | 1.31 bc | 0.109 d |
| Ca-4 | 6400 | 3.24 b | 0.153 d | 1.34 b | 0.157 a |

C - Complementary nutrients - N, P, K and Mg

Soil Nutrient Levels, Crop Yields, and the Chemical Composition of Soybean Plants as Affected by Three Levels of Complementary Nutrients Associated with Five Levels of Magnesium.

Soil Nutrient Contents

The soil test results that were associated with magnesium treatments are shown in Table 38. The use of complementary nutrients significantly increased the pH levels although no differences between the pH at C-2 and C-4 were noted. The tests for phosphorus increased with each level of complementary nutrients. This also occurred in the tests for potassium and calcium, although the differences in tests for potassium between C-0 and C-2 were not statistically significant. The test for magnesium increased and then decreased with increasing rates of complementary nutrients. This undoubtedly reflects some of the original variations in the magnesium content of the soil that was used in this experiment.

The use of magnesium at the high rates of 400 and 800 pounds per acre increased the pH level 0.2 units. The levels of phosphorus, potassium, and calcium were not affected by the use of magnesium. The soil test values for magnesium were increased at the Mg-3 and Mg-4 levels where 400 and 800 pounds per acre respectively had been used.

Crop Yields

The weights of leaves and stems were changed by the treatments only on the first sampling date. (Table 39) At this time the use of complementary nutrients at the highest level increased the weight of both the leaves and the stems. Magnesium had the general effect of decreasing the weight of the leaves and stems on the first sampling date.

The yields of seed were increased with the use of complementary nutrients approximately three bushels per acre. (Table 40) Yields at the C-4 level, however, decreased to the same range as was measured where no complementary nutrients were used. The use of magnesium did not affect seed yields except where the highest rate was used. In this case the seed yields were significantly reduced more than 2 bushels per acre.

Chemical Composition

The nitrogen levels in the leaves and stems are shown in Table 41. The levels in the leaf on the first sampling date were significantly increased by the use of complementary nutrients. Differences in nitrogen content were so small on August 3 that differences were not statistically significant. On August 30 the use of the highest rate of complementary nutrients significantly increased the nitrogen content of the leaves.

The highest nitrogen levels at the time of the first sampling occurred in the stems at the C-2 level. On August 3 the levels of nitrogen were very similar. However, by August 30 the use of the C-4 level of complementary nutrients resulted in significant increase in nitrogen contents.

The phosphorus content of the soybeans is shown in Table 42. The use of complementary nutrients increased the level of phosphorus in the leaves on all of the sampling dates. In the stems, the levels were similar on the first date except where the highest rate of complementary nutrients was used. On the second date, the quantities of phosphorus in the stems were similar. On the last date the use of the complementary nutrients increased the phosphorus contents. There was, however, no difference between the C-2 and C-4 levels.

The use of magnesium had a tendency to decrease the phosphorus levels in the leaves on the first sampling date. No differences were observed on the second date. However, by the last sampling time the use of magnesium tended to increase the quantity of phosphorus present even though in many instances it was not possible to measure differences that would be considered to be statistically significant.

In the stems no definite trend on any of the sampling dates could be established.

Potassium levels in the leaves and stems are shown in Table 43. The use of complementary nutrients increased the levels of potassium in both the leaves and stems. The differences in potassium levels in the leaves on the second sampling date resulting from the use of complementary nutrients at two rates were not statistically different.

The use of magnesium generally decreased the amount of potassium in the leaves and stems. Differences in the potassium contents associated with the various rates of magnesium tended to decrease with time. While the trend was present in the stems at the last sampling time, differences were not statistically significant.

The average calcium content of the leaves and stems is shown in Table 44. For any one sampling period only very small differences were measured. Nevertheless, statistically significant differences were measured. In the leaves the use of the high level of complementary nutrients caused an increase in the calcium content. This occurred on the first two sampling dates but not on the third. In the stems the use of the high rate of complementary nutrients significally increased the calcium level on all three dates.

The effects of increasing rates of magnesium on the calcium contents of leaves and stems were small. Because of this, it is doubtful that even these differences that were statistically significant have any value in interpreting what took place inside the plant.

The average magnesium contents of soybean leaves and stems are shown in Table 45. The use of complementary nutrients generally decreased the magnesium levels in both the leaves and stems on all three sampling dates. In the stems the average differences between the last two rates were not great enough to be considered statistically significant.

The use of magnesium increased the magnesium levels in both the stems and the leaves, although differences became less significant on the last sampling date. Increasing rates of magnesium generally increased magnesium levels in both the leaves and stems.

The total sugar and amino nitrogen values are shown in Table 46. In the leaves, the use of complementary nutrients at the C-2 level increased the total sugars. At the C-4 level the total sugar content was significantly lower than at the C-2. Increasing rates of complementary nutrients significantly reduced the total sugar content of the stems.

The use of magnesium increased total sugars in both the stems and leaves. At rates above Mg-3 (400 pounds per acre) in the leaves, and above Mg-1 in the stems, the levels of total sugars decreased.

The amino nitrogen was greatly and significantly increased in both the leaves and stems by the use of complementary nutrients. Such great differences masked the effect of the magnesium levels so that while statistically significant differences occurred, the values vary in such a way that interpretation is difficult.

## Discussion

The weights of both stems and leaves and the yields of soybeans were not improved with the use of magnesium because the soil used in these investigations initially contained sufficient quantities of exchangeable magnesium. The decrease in yield that was obtained where 800 pounds of magnesium per acre had been applied may be explained on the basis that magnesium suppressed the absorption of potassium by the soybean plants.

The concentration of magnesium in soybeans was decreased when used in combination with the complementary nutrient. This could be due to the antagonistic effect that potassium has on the absorption of magnesium. Prince et al. (78) in studying the release of magnesium from soils in New Jersey, concluded that the most important single factor influencing magnesium uptake by plants was the quantity of available potassium in the soil.

Several investigators reported that the use of magnesium increases the uptake of phosphorus. This tendency was found in the leaves on the last sampling date. Truog et al. (90) reporting on nutrient solution studies, suggested that both phosphorus and magnesium in peas increased appreciably and consistently with increasing concentrations of magnesium, and that increasing the supply of magnesium resulted in an increased level of phosphorus more than occurred when extra increments of phosphorus were used. In explaining the mechanism, Zimmerman (107) stated that magnesium may be a carrier of phosphate and therefore be closely related to phospholipid formation and to the synthesis of nucleoproteins in plant cells.

The decrease in concentration of potassium associated with the use of magnesium was also observed by Allen (3) and Evans et al. (27). The antagonistic relationship between magnesium and potassium was explained by Lundegardh (54).

The increased absorption of one cation was approximately balanced by a decreased absorption of another so that the total equivalent of cations in plant tissue remained essentially constant (53, 59, 81 and 93).

The increase of sugar content with the use of magnesium is in agreement with several investigators. VanHoot et al. (92) reported that low carbohydrate content was associated with low magnesium. Garner et al. (29) found that magnesium deficient tobacco leaves contained less carbohydrates than that did normal leaves. Shvyndenkov (82) suggested that Mg increased the content of maltose-like carbohydrate.

Table 38. - Average soil test results as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment | | | Available soil nutrients | | | |
|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Soil Reaction | Pounds Per Acre Phosphorus | Potassium | Calcium | Magnesium |
| C-0(Mg) | - | 7.2 b | 32 c | 84 b | 2930 c | 860 c |
| C-2(Mg) | - | 7.4 a | 57 b | 127 b | 3837 b | 936 a |
| C-4(Mg) | - | 7.4 a | 101 a | 345 a | 5157 a | 892 b |
| Mg-0 | 0 | 7.2 b | 63 a | 189 a | 3972 a | 857 c |
| Mg-1 | 100 | 7.2 b | 65 a | 191 a | 3911 a | 827 c |
| Mg-2 | 200 | 7.2 b | 66 a | 181 a | 3828 a | 867 c |
| Mg-3 | 400 | 7.4 a | 63 a | 196 a | 4189 a | 1140 b |
| Mg-4 | 800 | 7.4 a | 57 a | 170 a | 3972 a | 1206 a |

C - Complementary Nutrients - N, P, K and Ca

Table 39. - Average leaf and stem yields of soybeans at three stages of development as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment | | Dry Weight of 10 Plants (gms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Leaves | | | Stems | | |
| Nutrient Level Code | Rate Per Acre (Pounds) | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(Mg) | - | 1.83 b | 12.0 a | 60.4 a | 0.81 c | 6.7 a | 58.7 a |
| C-2(Mg) | - | 1.83 b | 13.4 a | 74.5 a | 0.83 b | 8.1 a | 72.5 a |
| C-4(Mg) | - | 2.0 a | 12.7 a | 78.7 a | 0.94 a | 7.4 a | 70.7 a |
| Mg-0 | 0 | 2.11 a | 13.2 a | 70.8 a | 0.95 a | 7.9 a | 67.5 a |
| Mg-1 | 100 | 1.84 b | 12.8 a | 71.1 a | 0.86 b | 7.3 a | 68.6 a |
| Mg-2 | 200 | 1.86 b | 12.4 a | 76.7 a | 0.83 c | 7.0 a | 69.7 a |
| Mg-3 | 400 | 1.86 b | 13.0 a | 71.7 a | 0.85 b | 8.0 a | 69.8 a |
| Mg-4 | 800 | 1.76 c | 12.0 a | 65.6 a | 0.80 d | 6.8 a | 61.4 a |

C - Complementary Nutrients - N, P, K and Ca

Table 40. - Average soybean seed yields as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Yield Per Acre (Bushels) |
|---|---|---|
| C-0(Mg) | - | 23.3 b |
| C-2(Mg) | - | 26.6 a |
| C-4(Mg) | - | 22.8 b |
| Mg-0 | 0 | 25.2 a |
| Mg-1 | 100 | 24.8 a |
| Mg-2 | 200 | 24.2 ab |
| Mg-3 | 400 | 24.6 a |
| Mg-4 | 800 | 22.3 b |

C - Complementary Nutrients - N, P, K and Ca

Table 41. - Average nitrogen content of soybean leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Mg) | - | 4.65 c | 5.34 a | 4.60 b | 2.91 c | 2.73 a | 1.85 b |
| C-2(Mg) | - | 5.06 b | 5.35 a | 4.77 b | 3.51 a | 2.62 a | 1.99 b |
| C-4(Mg) | - | 5.46 a | 5.37 a | 5.18 a | 3.15 b | 2.69 a | 2.74 a |
| Mg-0 | 0 | 5.14 a | 5.48 a | 4.95 a | 3.03 c | 2.73 a | 2.32 a |
| Mg-1 | 100 | 5.03 a | 5.22 a | 4.88 a | 3.26 a | 2.59 a | 2.23 a |
| Mg-2 | 200 | 5.12 a | 5.51 a | 4.85 a | 3.23 ab | 2.73 a | 2.11 a |
| Mg-3 | 400 | 5.08 a | 5.27 a | 4.73 a | 3.20 b | 2.64 a | 2.07 a |
| Mg-4 | 800 | 4.91 b | 5.29 a | 4.83 a | 3.23 ab | 2.73 a | 2.23 a |

Nitrogen in Soybean Tissue (per cent)

C - Complementary nutrients - N, P, K and Ca

Table 42. - Average phosphorus content of leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Phosphorus in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Mg) | - | 0.247 c | 0.385 c | 0.295 b | 0.181 b | 0.245 a | 0.172 b |
| C-2(Mg) | - | 0.288 a | 0.418 b | 0.330 ab | 0.176 b | 0.233 a | 0.227 a |
| C-4(Mg) | - | 0.280 b | 0.452 a | 0.349 a | 0.190 a | 0.245 a | 0.241 a |
| Mg-0 | 0 | 0.305 a | 0.433 a | 0.296 b | 0.180 bc | 0.249 a | 0.220 ab |
| Mg-1 | 100 | 0.267 b | 0.395 a | 0.325 ab | 0.175 c | 0.237 a | 0.203 b |
| Mg-2 | 200 | 0.262 b | 0.431 a | 0.306 ab | 0.200 a | 0.224 a | 0.197 b |
| Mg-3 | 400 | 0.262 b | 0.424 a | 0.355 a | 0.187 b | 0.253 a | 0.237 a |
| Mg-4 | 800 | 0.263 b | 0.408 a | 0.342 a | 0.168 d | 0.243 a | 0.209 ab |

C - Complementary nutrients - N, P, K and Ca

Table 43. - Average potassium content of leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| | | Potassium in Soybean Tissue (per cent) | | | | | |
| C-0(Mg) | - | 1.67 c | 1.33 b | 1.10 c | 1.57 c | 2.07 c | 1.17 c |
| C-2(Mg) | - | 2.31 b | 1.92 a | 1.59 b | 2.84 b | 3.40 b | 2.03 b |
| C-4(Mg) | - | 2.51 a | 2.00 a | 1.73 a | 3.33 a | 3.83 a | 2.33 a |
| Mg-0 | 0 | 2.40 a | 1.91 a | 1.61 a | 2.92 a | 3.34 a | 1.92 a |
| Mg-1 | 100 | 2.12 b | 1.78 ab | 1.44 b | 2.40 c | 3.13 ab | 1.88 a |
| Mg-2 | 200 | 1.98 c | 1.73 bc | 1.48 ab | 2.42 c | 3.01 ab | 1.86 a |
| Mg-3 | 400 | 2.33 a | 1.76 ab | 1.48 ab | 2.74 b | 3.13 ab | 1.77 a |
| Mg-4 | 800 | 1.99 c | 1.58 c | 1.37 b | 2.42 c | 2.88 b | 1.79 a |

C - Complementary nutrients - N, P, K and Ca

Table 44. - Average calcium content of leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment Nutrient Level Code | Rate Per Acre (Pounds) | Calcium in Soybean Tissue (per cent) Leaves July 12 | Leaves August 3 | Leaves August 30 | Stems July 12 | Stems August 3 | Stems August 30 |
|---|---|---|---|---|---|---|---|
| C-0(Mg) | - | 1.33 b | 1.61 b | 1.77 a | 1.41 c | 1.51 b | 0.94 b |
| C-2(Mg) | - | 1.31 b | 1.61 b | 1.75 a | 1.52 b | 1.56 b | 0.98 b |
| C-4(Mg) | - | 1.53 a | 1.77 a | 1.85 a | 1.77 a | 1.70 a | 1.07 a |
| Mg-0 | 0 | 1.46 a | 1.64 a | 1.79 ab | 1.57 c | 1.58 ab | 1.03 ab |
| Mg-1 | 100 | 1.41 b | 1.69 a | 1.86 a | 1.61 b | 1.65 a | 1.08 a |
| Mg-2 | 200 | 1.43 ab | 1.69 a | 1.81 a | 1.70 a | 1.63 a | 1.07 a |
| Mg-3 | 400 | 1.32 c | 1.62 a | 1.79 ab | 1.49 d | 1.51 b | 0.97 bc |
| Mg-4 | 800 | 1.34 c | 1.66 a | 1.70 b | 1.47 d | 1.57 ab | 0.94 c |

C - Complementary nutrients - N, P, K and Ca

Table 45. - Average magnesium content of leaves and stems at three stages of development as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment | | Magnesium in Soybean Tissue (per cent) | | | | | |
|---|---|---|---|---|---|---|---|
| Nutrient Level Code | Rate Per Acre (Pounds) | Leaves | | | Stems | | |
| | | July 12 | August 3 | August 30 | July 12 | August 3 | August 30 |
| C-0(Mg) | - | 0.519 a | 0.719 a | 0.639 a | 0.331 a | 0.553 a | 0.570 a |
| C-2(Mg) | - | 0.436 b | 0.484 b | 0.393 b | 0.277 b | 0.352 b | 0.356 b |
| C-4(Mg) | - | 0.379 c | 0.391 c | 0.378 b | 0.264 c | 0.345 b | 0.308 b |
| Mg-0 | 0 | 0.402 d | 0.398 c | 0.414 bc | 0.220 e | 0.340 c | 0.352 b |
| Mg-1 | 100 | 0.413 c | 0.517 b | 0.400 c | 0.280 d | 0.363 c | 0.427 ab |
| Mg-2 | 200 | 0.457 b | 0.497 b | 0.494 ab | 0.343 a | 0.401 bc | 0.381 ab |
| Mg-3 | 400 | 0.459 b | 0.660 a | 0.512 a | 0.298 c | 0.472 ab | 0.431 ab |
| Mg-4 | 800 | 0.493 a | 0.585 a | 0.580 a | 0.312 b | 0.508 a | 0.466 a |

C - Complementary nutrients - N, P, K and Ca

Table 46. - Average total sugar and amino nitrogen contents of soybean leaves and stems (flowering stage) as affected by three levels of complementary nutrients associated with five levels of magnesium.

| Treatment | | Total sugar and amino nitrogen in soybean tissue (per cent) | | | |
|---|---|---|---|---|---|
| | | Leaves | | Stems | |
| Nutrient Level Code | Rate Per Acre (Pounds) | Total Sugar | Amino Nitrogen | Total Sugar | Amino Nitrogen |
| C-0(Mg) | - | 3.03 c | 0.104 c | 1.78 a | 0.078 c |
| C-2(Mg) | - | 3.39 a | 0.164 b | 1.33 b | 0.116 b |
| C-4(Mg) | - | 3.26 b | 0.192 a | 1.08 c | 0.178 a |
| Mg-0 | 0 | 2.85 d | 0.150 b | 1.24 d | 0.103 d |
| Mg-1 | 100 | 3.33 b | 0.157 a | 1.53 a | 0.131 b |
| Mg-2 | 200 | 3.43 a | 0.160 a | 1.45 b | 0.142 a |
| Mg-3 | 400 | 3.42 a | 0.142 c | 1.44 b | 0.110 c |
| Mg-4 | 800 | 3.12 c | 0.160 a | 1.32 c | 0.130 b |

C - Complementary nutrients - N, P, K and Ca

# SUMMARY AND CONCLUSIONS

The field experiment was established on a Conover silt loam soil in 1960 to determine the effect of widely varying rates and combinations of nitrogen, phosphorus, potassium, calcium, and magnesium upon the growth, yield, and chemical characteristics of soybeans.

Each of the nutrients was applied at five rates. Each nutrient was associated with three rates of complementary nutrients. Soil samples were collected six weeks after fertilizer was applied. These samples were tested for pH, available phosphorus, and exchangeable potassium, calcium, and magnesium.

Plants were harvested at three stages of development which were labeled as "early vegetative," "flowering" and "pod-forming." The plant samples were divided into two groups, the leaves and the stems. Each of the samples was analyzed for nitrogen, phosphorus, potassium, calcium, and magnesium. Total sugar and amino nitrogen evaluations were made on samples that were collected during the flowering stage.

The results of these investigations are summarized as follows:

A. Yield

1. The use of ammonium nitrate increased the seed yield of soybeans approximately five bushels per acre. It

was concluded that nitrogen obtained by the soybean plant through fixation was inadequate for maximum growth and yield.

2. The use of triple superphosphate at rates up to 200 pounds of phosphorus per acre increased the dry weight of both leaves and stems. The yield of seed was significantly increased by the 200 pound application of phosphorus. The use of rates above this reduced the uptake of potassium which tended to be reflected in reduced seed yields.

3. The use of potassium chloride at high rates resulted in a decrease in the dry weights of leaves and stems. Soybean seed yields were not significantly increased by the application of potassium chloride. Where 1200 pounds per acre was used, the yield was significantly decreased. The application of potassium chloride resulted in a reduction in the uptake of magnesium and nitrogen. This probably accounts for the depression in yield.

4. The use of calcium hydroxide did not greatly affect the yield of either leaves or stems. Seed yields were increased where 800 pounds per acre was applied to the soil. The use of more than this did not affect seed yields.

5. The use of magnesium oxide at high rates decreased the dry weights of both leaves and stems. Seed yields were significantly lower where the application equaled 800 pounds of magnesium per acre. The application at this rate decreased the accumulation of potassium which probably caused the depression in yield.

6. The use of each nutrient except potassium associated with "medium" levels of complementary nutrients resulted in significantly higher seed yields than were produced where the "high" levels of complementary nutrients were used.

B. Chemical composition--leaves versus stems

1. The leaves contained more nitrogen, phosphorus, calcium, and magnesium than did the stems. The potassium content of the leaves was much lower than that found in the stems. At the flowering stage, the leaves in general contained more total sugars and alpha amino nitrogen than did the stems.

C. Chemical composition--stage of plant development

1. The nitrogen content of the leaves did not vary greatly during the growing season while the nitrogen content of the stems decreased during this time.

2. Phosphorus levels in both the leaves and the stems

increased up to the flowering time and then decreased during the pod-filling period.

3. In the leaves, potassium levels decreased as the growing season progressed. In the stems, potassium levels increased up to flowering time and then decreased during the pod-filling stage.

4. The levels of calcium in the leaves increased with time while they decreased in the stems.

5. Magnesium levels in both the leaves and stems did not exhibit any strong trend.

D. Chemical composition--nutrient levels in plant tissue

1. Nitrogen applied to the soil significantly increased the nitrogen content of both the leaves and the stems.

2. Applications of nitrogen resulted in an increase in calcium and magnesium levels in the plant. The use of highly active nitrate ions accelerated the uptake of the less active calcium and magnesium ions.

3. The use of nitrogen resulted in lower total sugar and higher alpha amino nitrogen levels. This was probably due to the role nitrogen plays in the formation of amino acid from alpha ketoglutaric acid.

4. Triple superphosphate applied to the soil at the rate of 400 pounds per acre of phosphorus significantly increased the phosphorus content of the leaves and

stems. When less than 400 pounds was used, phosphorus levels in the tissue were not increased greatly but the treatment did contribute to plant growth and yield.

5. The use of triple superphosphate resulted in increased accumulation of the divalent ions, calcium and magnesium. This was associated with a lower concentration of potassium. Differences in the accumulation of cations by soybeans are attributed to the morphology and physiology of the roots.

6. The application of phosphorus increased the total sugar and alpha amino nitrogen contents of soybean plants. Phosphorus is thought to increase the efficiency of carbon dioxide utilization. In addition, this element is essential for phosphorylation reactions which could aid in the formation of alpha amino acids.

7. Potassium chloride applications to the soil resulted in an increase in potassium levels in both the stems and the leaves.

8. Lower levels of nitrogen in both the leaves and stems were found where the potassium chloride was used. Heavy applications of potassium chloride apparently retarded nodule formation, thus decreasing the amount of nitrogen fixed.

9. Magnesium levels in both the leaves and stems were reduced where potassium chloride was used.

10. Potassium chloride applied at rates up to 300 pounds per acre increased the total sugar content of both the leaves and stems. At higher rates, the quantity of total sugars decreased. The explanation of this is related to the effect potassium has on the polymerization rate of sugar to starch or other complex carbohydrates. Low rates of polymerization are associated with low levels of potassium. Potassium also plays an essential role in the synthesis of proteins from amino acids. This would account for the decrease in amino acid content observed in this study.

11. The effect of calcium hydroxide applications upon the calcium content of leaves and stems was slight and not consistent.

12. The use of high rates of calcium had a tendency to reduce the magnesium levels in both the stems and the leaves.

13. The use of calcium up to the rate of 800 pounds per acre increased the total sugar content of both the leaves and the stems. Calcium hydroxide applications increased the amino nitrogen content slightly in both the leaves and the stems.

14. The use of magnesium hydroxide generally increased the magnesium level in both the leaves and the stems.

15. The application of magnesium tended to increase the accumulation of phosphorus in the soybean leaves. Magnesium is thought to act as a carrier of phosphate.

16. The application of magnesium decreased the concentration of potassium in the leaves and stems of soybeans. An antagonistic relationship between potassium and magnesium was observed.

17. The use of magnesium hydroxide had a general effect of increasing total sugar contents of the leaves and stems.

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*Obtained from the article, "Mineral nutrition of Soybeans" by A. J. Ohlrogge. Advances in Agronomy. 12:231-263. 1960.

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