RELATIONSHIPS BETWEEN APPLIED NUTRIENTS, PLANT COMPOSITION, AND YIELD OF BEANS (P. VULGARIS, L., VAR. SANILAC) AND WHEAT (T. VULGARE ALBORUBRUM, KOERN VAR. GENESEE)

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by

KULDIP SINGH BAINS

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of
Michigan State University of Agriculture and
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KULDIP SINGH BAINS ABSTRACT

A study was initiated in 1956 with field beans and wheat to determine relationships between applied nutrients, plant composition, and yield. The experimental work was carried out on a Sims loam soil to which nitrogen, phosphate, and potash were applied at specified levels and in various combinations. Different plant parts were sampled for chemical analysis.

Additional increments of nitrogen, phosphate, and potash increased the concentrations of nitrogen, phosphorus, and potassium, respectively, in beans and wheat plant tissues as well as in wheat grain. Concentrations of other elements were affected by these changes. Inter-relationships of a high degree, which varied with the crop species, were found.

Applied nitrogen significantly increased the calcium and magnesium concentrations in the wheat plants and in the grain. Nitrogen additions also increased the magnesium levels in the bean plants.

The nitrogen contents of the bean plants, wheat plants, and wheat seed were highly correlated directly with the calcium and magnesium concentrations. An inverse relationship existed between the potassium and magnesium contents of bean plants. This relationship was not present in the wheat. The phosphorus contents of wheat plants and grain were directly related to the magnesium concentrations. No such association was present in the bean plants. A direct relationship between the potassium versus calcium and magnesium contents of wheat grain was present. Moreover, positive inter-relationships between calcium, magnesium, and sodium concentrations were noted in the wheat but not in the beans.

Successive increments of applied nitrogen increased the bean yields but lowered wheat yields when used at rates in excess of 20 pounds per acre. No response to potash fertilization was observed for the wheat crop.

The estimated coefficients of regression for nitrogen, phosphorus, calcium, and sodium concentrations in the bean plants, in multiple regression analysis to estimate yield, were significant. It indicated that applied nutrients affected bean yields by changing plant chemical composition. Furthermore, it was shown that the chemical composition of wheat grain was closely related to the yield. The estimated coefficients of regression for per cent nitrogen, phosphorus, and potassium in wheat grain, in multiple regression analysis to predict yield, were significant.

Practical application of the data suggest that the chemical composition of plants or grain is a more reliable basis for predicting crop yields than are applied nutrients or soil test values.

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Justus von Liebig (41)* first advanced his mineral theory of plant nutrition in 1840. Since that time considerable attention has been devoted to this aspect of soil fertility in solving practical problems related to crop production. He first demonstrated the essential nature of potassium for plant growth. The list of essential elements for plant growth since then has considerably enlarged and now include 16 or more elements. Nitrogen, phosphorus, and potassium occupy prominent places in this list due to the significant role which these elements play in the metabolic processes of a plant during its life cycle as well as to the large amounts utilized by crop species.

It is well recognized that soil is a highly complex dynamic system. Soils differ in their physical, chemical, and biological properties, and are classified on the basis of these properties. They may be grouped and integrated on the transient similarity of these properties. Variations in chemical properties impart to the soil (types) the inherent capacity to supply available nutrients in varying amounts for plant growth.

The final yield of a crop is the outcome of three factors: (1) The genetic constitution and internal

*Numbers in parentheses refer to literature cited.

environment of a plant; (2) The soil with its complex environment which reflects artificial amendments and management practices; (3) The climatic and environmental factors associated with the geographic location of the soil. These factors influence individually and through their interactions the response of a crop to a given management practice. This complexity makes difficult the task of establishing clear cut relationships between soil and plant.

Liebig's statement (41) "by the deficiency or absence of one necessary constituent, all others being present, the soil is rendered barren for all those crops to the life of which that one constituent is indespensible" is the basis for the "law of the minimum." Later the concept of "available nutrients" was developed. In considering available nutrients in the soil, Spurway (36) stressed the importance of "level and balance" for maximum production. He pointed out that fertilization should both raise the level of nutrients and bring them into a better physiological balance for a plant. Studies by Power _et_ _al_. (29) suggest that crops differed in their behavior to unbalanced nutrient levels, and that "nutrient level and balance" cause changes in plant composition. This suggests need for expansion of research programs to better understand the relationships between applied nutrients, plant composition, and yield.

The purpose of this research was to examine relationships between applied nutrients, chemical composition, and the yield of field beans and wheat. This was a field, greenhouse, and laboratory project.

LITERATURE REVIEW

The importance of applied nitrogen, phosphorus, and potassium in successful crop production is well recognized. This is evident in the extensive and ever increasing use of these elements in synthetic fertilizers and the attention given to these in soil fertility programs. A voluminous amount of literature has accumulated on the inter-relationships of various plant nutrients and their effect on the composition of specific crops. A complete coverage of the subject is beyond the scope of this manuscript. The literature review is, therefore, restricted to the relationships generally accepted for the elements studied with particular reference to the wheat and bean crops.

Von Liebig (41) revolutionized plant nutrition concepts and thought by advancing the mineral theory of nutrient uptake. He suggested mineral analysis of plant ash in order to determine nutrient removal from the soil by a crop and further to replenish the nutrients thus taken up by the application of synthetic fertilizers. By 1855 Liebig's theory for the determination of nutrient needs of a crop on the basis of these tests was disproved. Further studies added the concept of plant nutrients absorbed by the soil complex which are considered to be available for plant use.

This concept lead to the development of soil tests for "available plant nutrients."

Shear _et al_. (33) considered "nutrient-element-balance" as a fundamental concept in plant nutrition. He defined "nutrient-element-balance" as the relative balance and intensity of nutrient elements that provide for the optimum desired growth.

Lundegarth (20) and Emmert (14) emphasized the relationship between nutrient concentration within the plant and yield. They used this concept to predict the response of a crop to applied nutrients. Legatu and Maume (18) advocated a procedure of comparative nutrient need diagnosis. They used foliar chemical analysis of poor, low yielding plants, and healthy, high yielding plants. Macy (21) and Ulrich (38) used foliar analysis and developed methods to determine "critical concentrations" of a nutrient element below which the crop would theoretically respond to the fertilizer containing that element.

In soil fertility research it is common to determine soil reaction as it indicates, in general, the availability of many plant nutrients, e. g. phosphorus, manganese, and boron. Cherng _et al_. (7) in research on soil reaction concluded that pH values may be transposed into corresponding H^+ ion concentrations and averaged to find sample means. They suggested, however, that pH values may be used for other statistical analysis as soil reaction in H^+ ion form lacks normal distribution.

So far as the mineral content of plants is concerned, a generalized trend of the variations in relationships between soil fertility and plant composition was diagramed by Beeson (1). This diagram shows a varying effect of nutrients applied to the soil on the mineral content of plants. Furthermore, it was shown that fertilizer response was a function of soil characteristics as well as fertilizer itself.

Data from many investigations suggest that applied nitrogen increases the per cent nitrogen in plants, especially where higher rates have been used. Black (3) recorded increases in yield of wheat in 12 out of 15 experiments. The nitrogen content of both grain and straw was appreciably increased.

Smith (34) found that applied nitrogen and phosphate increased forage yields of wheat whereas potash had no significant effect. Applied nitrogen increased the per cent nitrogen in the forage while decreasing the per cent phosphorus and potassium. The calcium content decreased where levels up to 30 pounds of nitrogen per acre had been used but increased linearly for greater amounts of applied nitrogen. The use of phosphate fertilizer increased the per cent phosphorus in the plant but had no effect on nitrogen, potassium, or calcium contents. Potash had no effect on the nitrogen content but increased the potassium content and decreased the calcium content of the plants.

Williams *et al*. (45) found that the use of nitrogen and phosphate fertilizers increased wheat yields whereas the use of potash had no effect. The protein content of grain increased with the application of nitrogen alone or in combination with phosphorus and/or potash fertilizer. This tendency was most pronounced with heavier applications of nitrogen.

Investigations on the effect of phosphate fertilizer utilization by various species have shown less change in plant composition. Blair and Prince (4) found only a slight increase in the phosphorus content of alfalfa where fertilizer phosphate had been used. Williams (46) showed that the application of superphosphate increased the total phosphorus content of wheat, field beans, and sugar beets. Wedin *et al*. (44) observed the same effect.

Truog *et al*. (37) found that the phosphorus content in peas was increased by the application of phosphate fertilizer. An increase in the phosphorus content was also noted with an increase in the supply of available magnesium. An increase in applied magnesium resulted in a greater uptake of phosphorus than was obtained by adding phosphorus to the media. Beeson (2) observed a positive correlation between phosphorus and magnesium contents of plants.

Sufficient data on the potassium content of agronomic plants are available to show that the potassium content of plant tissue varies widely with plant species. Van Slyke (40), and Morrison (24) have compiled data pertaining to the average potassium contents of several agronomic and horticultural crops. Important factors contributing to this variability were the level of exchangeable potassium in the soil, the level and balance of other nutrients, the physical conditions of the soil as related to air and water, and the variety of the species under consideration.

Snider (35) reported an increase of about 100 per cent in the potassium content of wheat and oat straw as a result of potash fertilization on four Illinois soils relatively low in available potassium. Drake _et al_.(10) recorded a several fold increase in the potassium content of wheat, barley, and oat plants grown where potash had been applied.

Fraser (16) noted very little effect on the growth of bean plants fertilized with potassium. However, the potassium uptake was significantly increased and was accompanied by a decrease in the magnesium and calcium contents. In this study potassium additions, significantly increased the cation content of the bean plants on five soil types.

Many other investigators (13, 22, 25) working on different crops have reported an increase in the potassium content of plants which were grown on soils which had been treated with potassium containing salts.

In a critical evaluation of soil fertility as it influences uptake of various elements by a plant, it is logical and necessary to separate the interactive effects of other important ions that enter into the composition of a plant. This, however, is not possible in most cases. There are considerable data to substantiate the statement that significant changes in the level and balance of any of the plant nutrients cause changes in the plant composition. Spurway (36), Shear *et al.* (32, 33), and many other workers have therefore emphasized the importance of "nutrient level and balance" and "nutrient-element-balance" in plant nutrition.

The concentration of potassium in a plant is generally reduced if the soil has a low level of available potassium and if only nitrogenous and phosphatic fertilizers are used. This reduction in the potassium concentration may be attributed to the increased growth as a result of nitrogen-phosphorus fertilization and the dilution of potassium within the plant.

Lorenz (19) working on the potato crop found that the use of nitrogen decreased the per cent potassium. Lawton *et al.* (17) recorded a 0.2 per cent reduction in the potassium content of legume hay when superphosphate was applied to soils already treated with potash. The removal of potassium by the first cutting hay was 72 pounds on the phosphate plus potash plots but only 55 pounds on the potash plots.

Drouineae *et al.* (12) working with corn, beans, and peas observed that the potassium content of the plant after six weeks depended primarily on the potassium concentration of the nutrient solution. The calcium content was reduced by increasing the concentration of potassium in the nutrient solution, even in the presence of large quantities of calcium carbonate.

Van Itallie (39) studied the influence of various levels and balance of exchangeable calcium, magnesium, potassium, and sodium on the cations absorbed by oat plants. He found that the uptake of potassium was affected only by the rate of potassium fertilizer used.

Boynton and Burrel (5) in a study on apple trees noted that an increased potassium uptake caused a magnesium deficiency. Walsh and Clarke (42) had similar results with tomato plants. Carlous (6) reported that potassium absorption by beans was primarily a function of the amount of applied potassium.

Walsh and O'Donohoe (43) in extensive studies upon the effect of potash fertilization on wheat, barley, and some other crops found that in most cases high potash fertilization induced magnesium deficiency even when this element was abundant in the soil. It was, therefore, concluded that the potassium-magnesium ratio of both soil and plant be considered in any study on magnesium deficiency.

Seatz (31) showed that bean yields were not affected by the application of potassium, magnesium, and certain micro-nutrients. Potash fertilizers influenced the magnesium contents of the bean plant, decreasing at high levels of potassium fertilization and increasing at low levels of potassium fertilization. An increase in the potassium content was recorded with the additions of potash.

Millar et al. (23) suggested that the location of the field bean area in Michigan and the lack of consistent response of this crop to commercial fertilizers might be due to the climatic factors. This is also substantiated by the data obtained by Davis (9). He recorded differential response of the bean crop to environmental factors under field and greenhouse conditions.

MATERIALS AND METHODS

Field experimental plots were established in Gratiot County on the Kenneth Thompson farm located two and one-half miles east of Ithaca in Section 4 of North Star Township. A typical rotation of beans, wheat, and corn was established with one crop grown on the plots each year. These plots were part of a project on nutrient level and balance studies and were designed particularly for an economic evaluation of the response obtained from the use of commercial fertilizers. The plots on this farm were used to study the relationships between applied nutrients, plant chemical composition, and crop yield.

Description of Soil

The soil, Sims loam, was developed under poor drainage conditions and, therefore, is relatively high in organic matter as indicated by the dark color of the surface soil. The field is both tiled and open ditch drained, but the tight subsoil impedes the rate of water removal. This soil type is considered to be one of the more productive in Michigan.

Experimental Design

The field experiment employed 258 individual plots in an incomplete 7 x 7 x 7 factorial design. This project included a 3 x 3 x 3 factorial with two replications for the first, fourth, and sixth treatment levels, and the rest of the treatments at other specified levels and combinations. The design was considered appropriate for the study of inter-relations or inter-actions for several rates and ratios of the fertilizer elements, and to estimate the effect of fertilizer elements on crop yields by constructing a continuous production function for the data thus obtained.

Fertilizer Materials and Rates

The fertilizer materials included ammonium nitrate (33.5%N), triple superphosphate (45% P_2O_5), and potassium chloride (60% K_2O). Fertilizer rates and ratios were the same for each crop in the crop sequence. The seven nutrient levels, including the "0" level, and the rates of application in the field experiments are listed as follows:

Nutrient	Level and Rate in Pounds per Acre						
	0	1	2	3	4	5	6
N:	0	20	40	80	160	240	320
P_2O_5 :	0	40	80	160	320	480	640
K_2O :	0	20	40	80	160	240	320

The rate of application for each nutrient in the greenhouse experiments was doubled, taking note of the work by Cook (8) on the relationship of nutrient response under field and greenhouse conditions.

Experimental

Field Experiments

The bean experiment was planted on June 22, 1956 and harvested on September 26-27, 1956. The Sanilac navy bean variety was planted in the experiment using 40 pounds of seed per acre. All of the nitrogen and potash was broadcast and plowed down before planting. Similarly all but 40 pounds of phosphoric acid was broadcast and plowed down on those plots receiving superphosphate. The 40 pounds of phosphoric acid not plowed down was applied as a starter fertilizer at planting time and was placed one inch to the side and one and one-half inches below the seed.

Wheat was planted on October 4, 1956, keeping the same plot boundries and experimental layout, and was harvested on August 5-6, 1957. The fertilizer treatments were made as has been described for beans except that at the planting time phosphate was located in contact with the wheat seed.

Grain harvest for field beans and wheat were made with a self-propelled combine.

Greenhouse Experiments

Soil from each of the field plots was brought in the greenhouse, air dried, screened through a 2 mm screen, and then thoroughly mixed. A 15,500 gram sample of soil was used for each pot. The fertilizer was mixed with the entire sample. The soil was then placed in a cellophane lined four gallon tin container. The Sanilac navy bean variety was planted in these cans during the third week of February, 1956 and the crop harvested on April 29, 1956. The dry weight of plant material from each pot was recorded after drying in an oven at $90^{o}F$. to a constant weight.

After bean harvest, the soil was taken out of the pots, screened through a 2 mm screen, sampled for soil analysis, fertilized, and again placed in the cans for wheat planting. The planting was done on December 18-19, 1956 and harvested during the first week of April, 1957. Distilled water was added to each pot during the course of the greenhouse studies to maintain optimum moisture level for plant growth. The oven dry weights of straw and wheat heads were obtained.

Materials for Correlation Studies

Fifty-six of the treatments were selected for the study on the relationships between applied nutrients, plant composition, and yield. These plots included eight replications of each of the seven levels of nitrogen, phosphoric acid, and potash. The treatments are listed in Table VII (appendix).

Sampling Procedures

Soil Samples

The soil samples were collected from field plots before fertilizer treatments were made. Twenty cores of soil, each eight inches deep, were taken from each plot, composited, screened through a 2 mm screen, mixed, and subsampled. Representative soil sample from each pot of greenhouse soil was also taken before the fertilizer application for each crop.

Plant Material Samples

Five individual normal bean plants were harvested from each field plot on August 14, 1956. These were composited, dried in a drying chamber, ground, and mixed. A subsample was then collected for each plot and stored in sample bottles. Similarly all plants harvested from each pot in the greenhouse were collected, dried, and subsampled for chemical analysis.

Plant samples from the field experiment on wheat were taken on June 25, 1957. The crop was in dough stage. Three individual samples from one foot length row were collected for each plot and composited. The plant material was oven dried, ground, and a representative subsample taken. Seed samples were obtained at harvest from each plot, ground, and stored in cardboard boxes. Wheat straw and heads were collected separately at harvest in the greenhouse experiment and were handled in the manner already described.

Laboratory Studies

Laboratory studies included soil tests and plant material chemical composition determinations. Soil reaction, reserve phosphorus and potassium were determined for each soil sample. The whole plant and seed samples were analyzed for total nitrogen, phosphorus, potassium, calcium, magnesium, and sodium. The procedures followed in these determinations are briefly outlined as follows:

Soil Analysis Procedures

Soil reaction of each soil sample was determined in a 1:1 soil-water suspension using a Beckman pH meter with a glass electrode.

Available phosphorus and potassium was determined by the Spurway reserve test procedure (37). A soil-extracting solution of 1:4 ratio was employed using 0.135 N hydrochloric acid as an extracting agent. Phosphorus and potassium in the soil extracts were determined with the ammonium molybdate and cobaltinitrite procedures (15, 26), respectively.

Plant Material Analysis Procedures

The total nitrogen was determined on oven dried plant materials by the Kjeldahl method as outlined by Pierce and Haenisch (27) and modified by Prince (30).

Wet Digestion

The plant materials were oven dried. A two-gram subsample was weighed and wet ashed by the nitric acid-perchloric acid digestion procedure described by Piper (28). The crystalline residue was dissolved in 0.1 N hydrochloric acid, diluted to 100 milliliters, filtered through a Whatman

No. 42 filter paper, and saved for all chemical determinations.

Phosphorus concentrations in the stock solution were determined calorimeterically with the ammonium molybdate method using Fiske-Subarrow reagent (15). Magnesium determinations were made with the thiazole yellow procedure as outlined by Drosdoff and Nearpass (11).

Calcium, potassium, and sodium were determined from the stock solutions with the Beckman DU spectrophotometer equipped with a photomultiplier.

Analysis and Interpretation of Data

Variation is a general phenomenon in nature, especially with biological materials collected from different environments. This becomes very evident when plant species are influenced by a modified environment created by human action. Since variability in materials and their response to modified environment exists, the problem of evaluating effects and relationships between cause and effect arises. When causal factors are artificially introduced and can be controlled, these become independent variables. The effect of such factors can be evaluated if the result can be accurately measured.

It is well known that crop yields are influenced by fertilization. There is also considerable data to show that fertilization affects the chemical composition and yield of plants. It is feasible to use various rates and combinations of plant nutrients; to analyze chemically the plants that are grown; and to accurately evaluate yields. This leads to the problem of logically evaluating systematic and describable relationships, if any, between nutrient content of the soil, plant chemical composition, and yield of crops.

The primary concern in this thesis is to relate certain studied variables. In doing so statistics expressing variance relationships have been calculated. These include simple correlations and multiple correlations between studied variables. The main objective in the calculation of these statistics was to draw inferences with respect to populations by the study of random samples of treatments and materials. In quantifying these relationships tests of significance and errors of estimates for the appropriate statistics were calculated. It may be remembered that statistical procedures do not take care of the shortcomings inherent in the performance of an experiment. The calculated statistics define the relationships and place confidence limits which indicate the probability of occurrance of similar results, if the experiment is repeated again under the same conditions. Inter-relationships between applied nutrients, total plant nutrients, plant chemical composition, and yield were also evaluated by employing simple correlation procedures.

Regression equations were fitted to the data for predicting yields from the other studied variables in this investigation. The better the fit of a prediction equation, the closer will be the agreement between experimental values and the predicted values of Y (yield). This relationship is shown by the simple correlation coefficient between experimental and predicted Y's and in essence is the coefficient of multiple correlation denoted by the symbol "R." The square of this correlation coefficient, "R^2," indicates that portion of the variance in observed yields which is associated with the studied variables used in calculating that particular regression equation. The coefficients of multiple correlation and the coefficients of multiple determination were adjusted for the number of variables and observations included in the regression analysis and are denoted by the symbols "$\overline{R}$" and "$\overline{R}^2$," respectively.* The standard error of estimate for each prediction equation is also reported. The significance of these statistics was used in interpreting experimental results.

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* $\overline{R}^2 = 1 - (1 - R^2)\ (N-1\ /\ N - M)$ where N = number of observations, and M = number of variables.

RESULTS AND DISCUSSION

The Average Effect of Applied Nutrients on pH and Available Plant Nutrients in the Soil

Soil test information as to pH, available phosphorus, and available potassium is presented in Table VII (appendix). These tests were made on soil samples taken before fertilizer applications during 1956 and 1957. The average effects of applied nutrients on pH, available phosphorus, and available potassium for both field and greenhouse experiments are shown in Table VIII (appendix). In considering the greenhouse data it should be remembered that the amount of each nutrient element applied on the basis of pounds per acre was twice the amount applied in the field experiments. The data in Table VIII (appendix) show that under field conditions no change in pH occurred as a result of the use of commercial fertilizer. In the greenhouse experiment, however, an appreciable decrease in pH was recorded where heavy application of acid forming fertilizer salt, ammonium nitrate, was used.

A slight decrease in available phosphorus, as indicated by the soil test, occurred in 1957 as compared to 1956. (Table VIII, appendix.) This may be due to phosphorus fixation by the soil and to crop removal in addition to the dilution effect caused by deeper plowing for the wheat crop. An appreciable increase in the available phosphorus occurred in the greenhouse experiment. This ranged from 40 per cent at the lower level to as high as 400 per cent at the higher levels of applications. The limited amount of soil in a four gallon pot and the heavy phosphorus applications contributed to these results.

Potash fertilization also produced dissimilar results in the available potassium content in the soil under field and greenhouse conditions. The data in Table VIII (appendix) indicate a decrease of about 35 per cent in available potassium in the soil under field conditions during 1957 as compared to 1956 soil tests. The previously mentioned reasons for a reduction in phosphorus soil test levels together with leaching likely account for this reduction in potassium soil test levels. No appreciable change in available potassium was recorded in the greenhouse experiments where 0, 1, or 2 levels of potash fertilizer had been used. However, at higher levels of applied potassium an increase in the available potassium, as high as 400 per cent, was recorded. High potassium applications, a limited amount of soil, and the use of cellophane bags, to avoid leaching of plant nutrients in greenhouse experiments, may explain the high soil test levels for potassium.

None of the correlation coefficients between pH and the chemical composition of beans grown in the field were significant. Because of this, and because only slight variation in pH occurred in the field, no attempt was made to correlate pH with wheat composition and yield.

Results with Field Beans

The Average Effect of Applied Nutrients on Plant Composition and Yield of Beans

<u>Field Experiment</u>

The chemical composition of bean plants was affected by fertilizer treatments as is seen in Table IX (appendix). The data in Table X (appendix) indicate the average effect of applied nutrients on the chemical composition and yield of bean plants. The average yield and chemical composition refer to a given level of N, P_2O_5, and K_2O and disregards the levels of the other two applied nutrients.

Nitrogen applications at the rate of 40 pounds of nitrogen per acre resulted in a decrease in the nitrogen content of bean plants from 2.54 per cent to 2.35 per cent. Subsequent additions of nitrogen fertilizer increased the per cent of nitrogen in the plant tissue. It appears that nitrogen additions at lower rates of applications contributed more to crop growth and yield but resulted in lower nitrogen concentrations. Applied potash also resulted in an increase in the nitrogen content of the plants but the increase in nitrogen content was not consistent.

The phosphorus content of the bean plants increased with the use of higher rates of phosphate. Potash fertilization also increased the phosphorus content of the plants. The increase, however, was not consistent. The average phosphorus content at different levels of nitrogen varied.

The potassium fertilization increased the potassium content of the bean plants and varied from 1.49 per cent potassium at no fertilizer level to 3.11 per cent at the highest level. Phosphate applications also increased the potassium content of bean plants. The increase in potassium content at the higher levels of nitrogen, however, was inconsistent.

An increase in the calcium content of the bean plants was associated with nitrogen applications. Applied potassium, on the other hand, decreased the per cent of magnesium in the plants.

The average yield at different individual levels of applied nitrogen, phosphate, and potash reflected the fertilizer treatments; however, the response was not consistent over the wide range in levels of nutrients used.

Greenhouse Experiment

The data in Table XI (appendix) show the chemical analysis of bean plants grown in the greenhouse. The average effect of applied nutrients on the chemical composition and yield of beans is presented in Table XII (appendix). The changes in chemical composition were similar to those obtained under field conditions.

The nitrogen applications increased the nitrogen content of the plants. The calcium and sodium percentages in the plants increased in some cases, although the increases were not consistent with extra increments of nitrogen.

Applied phosphorus increased the phosphorus and potassium percentages in the plants. Potash fertilizer increased the potassium and calcium concentrations. A reduction in the magnesium content was associated with high potassium levels.

The yield response to the fertilizer treatments did not suggest any specific pattern. The data indicated that nitrogen applications increased the yield; however, the response of phosphate and potash was erratic.

Relationships between Applied Nutrients, Total Plant Nutrients, Chemical Composition and Yield of Beans

Field Experiment

The data presented in Table I indicate that highly significant correlations exist between pounds of applied nitrogen and percentages of nitrogen and calcium in the plants. A highly significant correlation coefficient existed between applied phosphorus and the phosphorus content of the plants. Also applied phosphorus was positively related to the potassium content. Applied potash was positively correlated with per cent potassium and phosphorus in plants. A significant correlation of -.391 was obtained between applied potassium and per cent magnesium in the plants tissue.

TABLE I

SIMPLE CORRELATION COEFFICIENTS BETWEEN APPLIED NUTRIENTS OR TOTAL PLANT NUTRIENTS, CHEMICAL COMPOSITION OF BEAN PLANTS, AND YIELD ON SIMS LOAM SOIL, 1956

Plant Nutrient	Elemental Composition of Bean Plants, (Per Cent) and Yield						
	N	P	K	Ca	Mg	Na	Yield
			Field Experiment[1]				
N_a	.642**	-.061	.195	.566**	.169	.175	.434**
P_a	-.106	.751**	.364**	.043	-.005	-.111	.232
K_a	.130	.292*	.792**	-.082	-.391**	.086	.267
$P_a + P_{st}$	-.100	.758**	.366**	.060	.001	-.093	.243
$K_a + K_{st}$	.192	.336*	.806**	-.077	-.381**	.031	.275*
			Greenhouse Experiment[2]				
N_a	.716**	-.106	.104	.656**	.023	.441**	.304*
P_a	.091	.813**	.366**	.106	-.039	.056	.100
K_a	-.076	.148	.800**	.385**	-.615**	.012	-.018
$P_a + P_{st}$	.101	.821**	.369**	.098	-.034	.047	.100
$K_a + K_{st}$	-.044	.165	.805**	.385**	-.593**	.013	-.052

[1]Chemical composition of entire bean plants and yield in bushels per acre.

[2]Chemical composition of entire bean plants and total dry matter yield in grams per pot.

"a"---Subscript refers to applied nutrient.
"st"--Subscript refers to Spurway reserve soil test results.
* Significant at 5 per cent probability level.
** Significant at 1 per cent probability level.

Only applied nitrogen gave a statistically significant correlation of .434 with bean grain yields. Applied phosphorus and potassium were not significantly correlated with yield.

Correlation coefficients between applied nutrients and composition were relatively high. However, it was theorized that the relationships might be improved if the supply of available nutrients in the soil, as measured with soil tests, were added to those supplied in the fertilizer. The term "Total Plant Nutrients" refers to a value obtained by adding together the equivalent fertilizer rates and soil test results from given field plot or greenhouse pot.

Simple correlation coefficients between the total plant nutrients, phosphorus and potassium, plant composition, and yield revealed the same relationships as stated above for applied nutrients. The correlation coefficient between total plant nutrient, potassium versus yield, improved slightly and was found to be significant.

Greenhouse Experiment

The correlations existing between plant nutrients, plant chemical composition, and yield are reported in Table I. The relationships as were present in the field agree very closely with those obtained in the greenhouse with certain deviations. A highly significant correlation between applied nitrogen and per cent sodium in the bean plant tissues was observed under greenhouse conditions whereas the correlation coefficient in the field experiment, though positive, was not sufficiently high for statistical significance.

Applied potassium was closely associated with the calcium content of bean plants in the greenhouse experiment. This was just the opposite as was obtained under field conditions, although the correlation coefficient in the latter case was not significant. The explanation for this is theorized to be related to the high application rates of potash. Potassium probably replaced calcium on the exchange complex and made it more available for plants uptake. The correlation coefficient between applied potassium versus phosphorus in the plants, though significant in field experiment, was not significant under greenhouse conditions. The total plant nutrient potassium also showed close association with the calcium content of greenhouse plants.

Applied nitrogen rates were closely related to the total dry matter yield. The phosphate and potash applications did not greatly affect yield.

Inter-relationships between Plant Composition and Yield of Beans under Field and Greenhouse Conditions

The inter-relationships between various chemical elements in the bean plants and yield in both the field and greenhouse experiments are presented in Table II.

TABLE II

SIMPLE CORRELATION COEFFICIENTS BETWEEN THE CHEMICAL COMPOSITION OF BEAN PLANTS AND YIELD ON SIMS LOAM SOIL, 1956

Elemental Composition (Per Cent)	Elemental Composition of Bean Plants (Per Cent) and Yield						
	N	P	K	Ca	Mg	Na	Yield
	Field Experiment[1]						
N	1.000	.172	.368**	.539**	.395**	.033	.657**
P		1.000	.565**	.029	.129	-.217	.497**
K			1.000	-.097	-.247	.009	.530**
Ca				1.000	.544**	.076	.483**
Mg					1.000	-.179	.195
Na						1.000	-.162
	Greenhouse Experiment[2]						
N	1.000	.135	-.110	.452**	.279*	.391**	.192
P		1.000	.226	-.046	.114	-.026	-.045
K			1.000	.244	-.628**	.087	-.074
Ca				1.000	.029	.317*	.029
Mg					1.000	-.044	-.067
Na						1.000	.254

[1]Chemical composition of entire bean plants and yield in bushels per acre.

[2]Chemical composition of entire bean plants and total dry matter yield in grams per pot.

* Significant at 5 per cent probability level.
** Significant at 1 per cent probability level.

Results recorded under field and greenhouse conditions varied widely. The nitrogen content of the bean plants showed highly significant positive correlations of .539 and .452 with calcium concentrations in the plants in the field and greenhouse experiments, respectively. Significant correlations between plant nitrogen versus magnesium contents were obtained under field and greenhouse conditions. This was also the case for nitrogen and potassium in the field but not in the greenhouse. Similarly, a highly significant positive correlation between the nitrogen contents of plant materials and the sodium was found in the greenhouse experiment but not in the field.

A highly significant correlation of .565 was found between the phosphorus and potassium contents of bean plants under field conditions. In the greenhouse experiment the correlation coefficient, though positive, failed to reach the 5 per cent level of significance.

Increases in the potassium content of the bean plants were associated with lower levels of magnesium. This relationship was much more evident in the greenhouse than in the field.

A highly significant correlation existed between the calcium and magnesium contents of the bean plants produced under field conditions. However, under greenhouse conditions the correlation coefficient was almost zero. Calcium contents were significantly correlated with the sodium percentages in the greenhouse experiment but not in the field.

Under field conditions total nitrogen, phosphorus, potassium, and calcium percentages in the plant tissues were significantly correlated with bean grain yields. Grain yields were not determined in the greenhouse experiment. The aerial portion of the plant was used as an indication of yield. None of the elements in the plant chemical composition showed any significant correlations with yield in the greenhouse. In this experiment the total dry matter of the aerial parts of the plants (yield) was not a satisfactory indicator of yield.

Predicting Bean Yields from Applied Nutrients, Soil Tests, and Plant Chemical Composition

The statistical estimates of bean yield were obtained from the other studied variables and are reported in Table XIII (appendix). In order to predict bean yield from the data pertaining to all studied variables, four sets of regression equations using different sets of studied variables were calculated. The first formulation of a functional relationship was obtained for a regression equation using applied nitrogen, phosphate, and potash and their square roots and the soil tests for phosphorus and potassium in pounds per acre and their square roots. The values listed below the estimated parameters and included in parentheses are standard errors of the respective parameters. The letters N, P, and K represent pounds per acre of applied nitrogen, phosphate, and potash, respectively. This designation is used in all equations unless otherwise indicated. The subscripts "a" and "st" identifies applied nutrients and soil test values, respectively. As was mentioned previously, "R^2" represents the square of the coefficient of multiple determination, "R" the coefficient of multiple correlation, "$\bar{R}^2$" the adjusted coefficient of multiple determination, "$\bar{R}$" the adjusted coefficient of multiple correlation, and "S" is the standard error of predicted yield. The coefficients of multiple correlation and determination were adjusted for the number of variables and observations included in regression analysis.

Equation I*--(Beans Grown in the Field)

$$\hat{Y}_b = 55.908287 + \underset{(.031444)}{.023058}\, N_a - \underset{(.642568)}{.067602}\sqrt{N_a} - \underset{(.123872)}{.002676}\, P_a$$

$$- \underset{(3.391241)}{.262449}\sqrt{P_a} - \underset{(.018822)}{.013998}\, P_{st} + \underset{(.558348)}{.641833}\sqrt{P_{st}}$$

$$+ \underset{(.228594)}{.238408}\, K_a - \underset{(5.977581)}{5.942793}\sqrt{K_a} - \underset{(.037174)}{.018841}\, K_{st}$$

$$+ \underset{(.706944)}{.338996}\sqrt{K_{st}}$$

$$R^2 = .309 \quad R = .556 \quad \bar{R}^2 = .145 \quad \bar{R} = .381 \quad S = 5.663$$

The adjusted coefficient of multiple correlation, $\bar{R}$, for this regression equation was .381. The coefficient of multiple determination, $\bar{R}^2$, indicated that about 15 per cent of the variance in bean yield under field conditions was

*N Equations I-IV = 53

associated with variance explained by the regression equation. None of the estimated coefficients in regression equation were significant.

Because of the large amount of variation not associated with the regression equation I and the nonsignificant magnitude of the various estimated parameters, a second prediction equation using applied nitrogen and total plant nutrients, phosphorus and potassium in the soil, was calculated. The subscript "t" denotes total plant nutrients as have already been defined.

<u>Equation II</u>--(Beans Grown in the Field)

$$\hat{Y}_b = -7.174048 + \underset{(.026188)}{.009998}\,N_a + \underset{(.525948)}{.202862}\sqrt{N_a} - \underset{(.024698)}{.010634}\,P_t$$

$$+ \underset{(.990171)}{.594509}\sqrt{P_t} - \underset{(.062870)}{.064775}\,K_t + \underset{(2.206401)}{2.421763}\sqrt{K_t}$$

$$R^2 = .306 \quad R = .553^{*} \quad \bar{R}^2 = .216 \quad \bar{R} = .464 \quad S = 5.424$$

The adjusted coefficient of multiple correlation for the above equation was .464 and the coefficient of multiple determination indicated that about 22 per cent of the variance in bean yields was associated with regression. Obviously neither equation I nor II is satisfactory for predicting yields. These analyses point out that other factors may be involved in the prediction of bean yields.

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*Significant at 5 per cent level in all equations.

**Significant at 1 per cent level in all equations.

A third regression equation for the estimation of bean yield from the chemical composition of bean plants was then calculated. In this equation the subscript "p" with each element means the per cent concentration of the element in the plant tissue.

<u>Equation III</u>--(Beans Grown in the Field)

$$\hat{Y}_b = -5.709550 + \underset{(1.863776)}{6.039279}\,N_p + \underset{(10.450081)}{26.258481}\,P_p$$

$$+ \underset{(1.219433)}{2.062404}\,K_p + \underset{(1.540321)}{5.651090}\,Ca_p - \underset{(4.373927)}{7.331778}\,Mg_p$$

$$- \underset{(385.801168)}{822.154901}\,Na_p$$

$R^2 = .701 \quad R = .837^{**} \quad \bar{R}^2 = .662 \quad \bar{R} = .814 \quad S = 3.560$

The adjusted coefficient of multiple correlation for the above equation was .814. The coefficient of multiple determination pointed out that about 66 per cent of the variance in bean grain yields under field conditions was associated with the regression. It indicated that bean grain yield was highly related to chemical composition of bean plants. In this equation, the coefficients for nitrogen, phosphorus, calcium, and sodium were significant. It is also seen that standard errors of estimates for phosphorus and especially for sodium were high. The explanation for this may be related to the low levels of these elements in the plant tissue.

Finally an attempt was made to use data on all studied variables and to calculate regression equation for

the prediction of beans yield under field conditions.

Equation IV--(Beans Grown in the Field)

$$\hat{Y}_b = -15.950286 - \underset{(.018563)}{.000664} N_a + \underset{(.359817)}{.050765}\sqrt{N_a}$$

$$- \underset{(.017257)}{.013578} P_t + \underset{(.697512)}{.571347}\sqrt{P_t} - \underset{(.040983)}{.039566} K_t$$

$$+ \underset{(1.445337)}{.899354}\sqrt{K_t} + \underset{(2.768745)}{5.927788} N_p + \underset{(18.156186)}{20.817640} P_p$$

$$+ \underset{(1.989522)}{4.380991} K_p + \underset{(1.825103)}{5.543207} Ca_p - \underset{(4.457576)}{9.298144} Mg_p$$

$$- \underset{(390.631619)}{897.094106} Na_p$$

$R^2 = .760 \quad R = .872^{**} \quad \bar{R}^2 = .688 \quad \bar{R} = .830 \quad S = 3.419$

The adjusted coefficient of multiple correlation for the above equation was .830. The coefficient of multiple determination indicated that about 69 per cent of the variance in bean yield was associated with regression.

In this equation coefficients for applied fertilizers were not significant. The coefficients for chemical contents of the plants in regard to the per cent nitrogen, potassium, calcium, magnesium, and sodium were significant. The significant coefficients of regression indicated that these variables had statistically significant effects on the yield of beans.

The bean experiment was duplicated in the greenhouse by using the soil from respective plots. Total dry matter in grams per pot was used as a measure of yield. The functional relationship between yield and variables studied is shown in the following regression equations.

Equation V*--(Beans Grown in the Greenhouse)

$$\hat{Y}_{dm} = -5.596713 - \underset{(.010300)}{.032370}\, N_a + \underset{(.293690)}{1.127787}\sqrt{N_a}$$
$$- \underset{(.080615)}{.123838}\, P_a + \underset{(1.923386)}{3.609915}\sqrt{P_a} + \underset{(.005918)}{.000666}\, P_{st}$$
$$- \underset{(.244191)}{.083962}\sqrt{P_{st}} - \underset{(.143107)}{.082308}\, K_a + \underset{(3.745132)}{1.413385}\sqrt{K_a}$$
$$+ \underset{(.011704)}{.011146}\, K_{st} - \underset{(.308663)}{.308005}\sqrt{K_{st}}$$

$R^2 = .467$ $R = .683^{**}$ $\bar{R}^2 = .337$ $\bar{R} = .580$ $S = 3.587$

The adjusted coefficient of multiple correlation was .580. The adjusted coefficient of multiple determination pointed that about 34 per cent of the variance in total dry matter yield was associated with regression. The first two coefficients in this regression equation were significant to the 1 per cent probability level. The rest of the coefficients were not statistically significant.

A second regression equation using applied nitrogen and total plant nutrients, phosphorus and potassium in the soil, was calculated.

Equation VI--(Beans Grown in the Greenhouse)

$$\hat{Y}_{dm} = 18.707342 - \underset{(.009141)}{.025415}\, N_a + \underset{(.254783)}{.895684}\sqrt{N_a}$$
$$- \underset{(.008669)}{.007489}\, P_t + \underset{(.434481)}{.392502}\sqrt{P_t} - \underset{(.020595)}{.005997}\, K_t$$
$$+ \underset{(.848390)}{.107825}\sqrt{K_t}$$

$R^2 = .414$ $R = .644^{**}$ $\bar{R}^2 = .336$ $\bar{R} = .580$ $S = 3.588$

*N Equations V-VIII = 52

The adjusted coefficient of multiple correlation was .580. The adjusted coefficient of multiple determination indicated that 34 per cent of the variance in yield was associated with the regression. In this equation the coefficients for applied nitrogen and its square root were also significant.

<u>Equation VII</u>--(Beans Grown in the Greenhouse)

$$\hat{Y}_{dm} = 24.776603 + \underset{(2.258208)}{2.261950}\ N_p + \underset{(8.333159)}{.471277}\ P_p$$

$$- \underset{(1.470443)}{1.443176}\ K_p - \underset{(.983500)}{.336255}\ Ca_p - \underset{(5.945183)}{7.039441}\ Mg_p$$

$$+ \underset{(431.888362)}{581.579344}\ Na_p$$

$$R^2 = .117 \quad R = .343 \quad \bar{R}^2 = 0 \quad \bar{R} = 0 \quad S = 4.404$$

The adjusted coefficient of multiple correlation and coefficient of multiple determination were zero. This indicated that the regression equation failed to associate any variance in dry matter yield with the regression. None of the coefficients were significant.

The prediction equation for dry matter yields under greenhouse conditions using applied fertilizer variables, soil tests, and plant chemical composition is presented in Equation VIII.

Equation VIII--(Beans Grown in the Greenhouse)

$$\hat{Y}_{dm} = 41.585487 - \underset{(.008959)}{.024874}\,N_a + \underset{(.253615)}{.993539}\sqrt{N_a}$$

$$- \underset{(.008519)}{.004677}\,P_t + \underset{(.430757)}{.394897}\sqrt{P_t} - \underset{(.024425)}{.003756}\,K_t$$

$$+ \underset{(1.095505)}{.006161}\sqrt{K_t} - \underset{(2.623747)}{1.599649}\,N_p - \underset{(12.559376)}{14.009516}\,P_p$$

$$- \underset{(1.631223)}{2.153397}\,K_p - \underset{(.895054)}{.965695}\,Ca_p - \underset{(4.959524)}{9.869729}\,Mg_p$$

$$+ \underset{(376.431511)}{63.792041}\,Na_p$$

$R^2 = .568 \quad R = .754^{**} \quad \bar{R}^2 = .435 \quad \bar{R} = .660 \quad S = 3.309$

The adjusted coefficient of multiple correlation was .660. The coefficient of multiple determination indicated that 44 per cent of the variance in total dry matter per pot was associated with regression. The only significant coefficients pertained to applied nitrogen.

Results With Wheat

The Average Effect of Applied Nutrients on Plant Chemical Composition and Yield of Wheat

Field Experiment

The data in Table XIV (appendix) show the chemical composition of entire plants at dough stage. The average effect of applied nutrients on the chemical composition of wheat plants and yield is presented in Table XV (appendix). The per cent of nitrogen in plant tissue increased with an increase in applied nitrogen. However, with the application of 20 pounds and 40 pounds of nitrogen per acre, a slight decrease in the concentration of nitrogen in wheat plants tissue was recorded. This might be expected as such moderate amounts of applied nitrogen would tend to accelerate more vegetative growth and thereby tend to dilute the nitrogen concentrations in plants tissue. No definite trend in the concentrations of nitrogen in plant tissues was recorded for successive levels of phosphate or potash applications.

The phosphorus content of the plants increased with successive applications of phosphate. Nitrogen and potash fertilizers did not consistently affect the phosphorus content. Potash fertilization increased the potassium content of the plants. The potassium content showed an increase at higher levels of nitrogen fertilization, whereas at lower levels, a depression in the potassium content occurred.

Nitrogen and phosphorus applications affected the calcium content of the wheat plants. The former increased and the latter decreased the calcium level. The magnesium and sodium contents increased with nitrogen applications.

Fertilizer applications, in general, showed no favorable effect on grain yields due to wet weather and severe lodging prior to harvest, especially in plots where high nitrogen rates were used. On the contrary, the use of nitrogenous fertilizer appreciably depressed the yield, especially at higher levels of application. Applied phosphate appeared to increase yields. Potash additions did not cause any yield variations.

The effect of the use of fertilizer on the chemical composition of wheat grain and yield is seen in Table XVI (appendix). The data in Table XVII (appendix) show the average effect of nitrogen, phosphate, and potash fertilizers. As nitrogen applications increased the per cent of nitrogen, phosphorus, potassium, calcium, and magnesium in wheat grain increased.

Phosphorus fertilization, in general, increased the phosphorus concentration in the seed. The use of potash fertilizer also increased the potassium content of the grain.

Greenhouse Experiment

The data in Table XVIII (appendix) show the chemical analysis of wheat straw and total dry matter yield. The average effect of applied nutrients on the chemical composition is presented in Table XIX (appendix). Increasing the amount of nitrogenous fertilizer applied, in general, increased the per cent of nitrogen, calcium, and magnesium in wheat straw.

A gradual increase in the phosphorus content of straw was recorded with each increment of phosphate fertilization. An increase in the magnesium content was also obtained with phosphate fertilization.

The use of potash increased the potassium and calcium concentrations in the straw.

Phosphorus applications, in general, increased the total dry matter yield (straw and heads). The nitrogen fertilizer increased the yield at lower levels of application but depressed the yield at the higher levels.

The individual chemical analysis and the average effect of applied nutrients on the chemical composition of wheat heads and total dry matter yield are shown in Tables XX and XXI (appendix), respectively. The data indicate that applied nitrogen, in general, increased the concentrations of nitrogen, potassium, calcium, magnesium, and sodium, in the wheat heads.

Applied phosphate and potash increased the phosphorus and potassium levels in the wheat heads. Phosphorus accumulation was depressed slightly at the higher rates, 960 and 1280 pounds per acre, of phosphate fertilization.

Relationships between Applied Nutrients, Total Plant Nutrients, Plant Composition, and Yield of Wheat

Field Experiment--(Analysis of Entire Plant)

The data presented in Table III indicate that highly significant relationships exist between applied nitrogen and the per cent of nitrogen, potassium, calcium, magnesium, and sodium in the whole wheat plant tissues. The relationship between applied phosphate and potash with the respective phosphorus and potassium contents of the plants was highly correlated but was not related to the concentrations of any other ion in the plants. The correlation coefficient between phosphorus and calcium was increased by adding the

TABLE III

SIMPLE CORRELATION COEFFICIENTS BETWEEN APPLIED NUTRIENTS, TOTAL PLANT NUTRIENTS, CHEMICAL COMPOSITION OF WHEAT PLANTS, AND YIELD ON SIMS LOAM SOIL, 1957

Plant Nutrient	Elemental Composition (Per Cent) and Yield						
	N	P	K	Ca	Mg	Na	Yield
Field Experiment[1]							
N_a	.872**	.258	.629**	.827**	.336*	.599**	-.733**
P_a	-.044	.746**	.073	-.255	.094	.133	.201
K_a	.117	.069	.480**	.007	-.142	-.090	-.095
$P_a + P_{st}$	-.080	.747**	.048	-.284*	.057	.110	.231
$K_a + K_{st}$	.050	.049	.491**	-.077	-.184	-.166	-.044
Greenhouse Experiment[2]							
N_a	.712**	.154	.074	.866**	.367**	.064	-.255
P_a	.199	.779**	-.040	.122	.375**	.232	.275*
K_a	.133	.230	.733**	.329*	.035	-.118	.057
$P_a + P_{st}$	.158	.707**	-.018	.122	.321*	.205	.241
$K_a + K_{st}$	.086	.208	.725**	.267*	.027	-.171	.051

[1]Chemical composition of entire wheat plants and yield in bushels per acre.

[2]Chemical composition of wheat straw and total dry matter yield in grams per pot.

"a" Subscript refers to applied nutrients.
"st" Subscript refers to Spurway reserve soil test results.

* Significant at 5 per cent probability level.
** Significant at 1 per cent probability level.

soil test value to the applied phosphate value. This procedure increased the coefficient to a statistically significant level.

Applied nitrogen was negatively correlated (-.733) with grain yield. Phosphorus fertilizer rates were positively correlated with yield, but failed to reach statistical significance at the five per cent probability level.

Greenhouse Experiment--(Analysis of Straw)

The data in Table III show that significant correlations existed between applied nitrogen and the nitrogen, calcium, and magnesium concentrations in the wheat straw. Phosphorus application rates were closely associated with the phosphorus and magnesium contents of the straw. Potash additions significantly increased the potassium and calcium contents of the straw.

The coefficient .275 indicates a positive relationship between applied phosphorus and the total dry matter per pot.

Field Experiment--(Analysis of Grain)

The relationships reported in Table IV indicate that significant correlations existed between applied nitrogen and the percentages of nitrogen, phosphorus, potassium, calcium, and magnesium in the wheat grain. Applied phosphate and potash were closely associated positively with the phosphorus contents of the seed. No improvement in the magnitude of correlation coefficients between total

TABLE IV

SIMPLE CORRELATION COEFFICIENTS BETWEEN APPLIED NUTRIENTS, TOTAL PLANT NUTRIENTS, CHEMICAL COMPOSITION OF WHEAT GRAIN, AND YIELD ON SIMS LOAM SOIL, 1957

Plant Nutrient	Elemental Composition (Per Cent) and Yield						
	N	P	K	Ca	Mg	Na	Yield
Field Experiment[1]							
N_a	.900**	.502**	.786**	.363**	.539**	.090	-.742**
P_a	-.091	.519**	.022	-.060	.050	.022	.197
K_a	.264	.291*	.205	.094	.024	.178	-.054
$P_a + P_{st}$	-.107	.535**	.035	-.066	.035	.007	.223
$K_a + K_{st}$	.199	.271*	.165	.072	.016	.159	-.003
Greenhouse Experiment[2]							
N_a	.406**	.024	.492**	.752**	.368**	.398**	-.255
P_a	-.123	.649**	.214	.066	.273*	.159	.275*
K_a	.034	.171	.427**	.182	-.002	.175	.057
$P_a + P_{st}$	-.144	.602**	.197	.062	.256	.156	.248
$K_a + K_{st}$	-.008	.136	.389**	.142	-.062	.144	.051

[1]Chemical composition of wheat grain and yield in bushels per acre.

[2]Chemical composition of wheat heads and yield of total dry matter in grams per pot.

"a" Subscript refers to applied nutrients.
"st" Subscript refers to Spurway reserve soil test results.

* Significant at 5 per cent level.
** Significant at 1 per cent level.

plant nutrients versus the elements in the grain were shown, over the one's obtained against applied nutrients.

Applied nitrogen was negatively associated with wheat gain yield.

Greenhouse Experiment--(Analysis of Spikes)

The data in Table IV show that highly significant correlations existed between applied nitrogen and the percentages of nitrogen, potassium, calcium, magnesium, and sodium in the spikes (wheat heads). Phosphorus applications were closely related to the per cent of phosphorus and magnesium in wheat heads. Potash additions were significantly correlated with the potassium content of the wheat heads. Highly significant correlations were obtained between the total plant nutrients, phosphorus and potassium in the soil, versus their respective concentrations in the heads, but did not show any improvement over those coefficients for applied nutrients.

Inter-Relationships between the Chemical Composition and Yield of Wheat

Field Experiment

The data in Table V show that significant relationships existed between the per cent nitrogen in the wheat plant tissues and the concentrations of phosphorus, potassium, calcium, magnesium, and sodium. A significant association existed between the plant phosphorus and the

TABLE V

SIMPLE CORRELATION COEFFICIENTS BETWEEN THE CHEMICAL COMPOSITION OF WHEAT PLANT MATERIALS AND YIELD ON SIMS LOAM SOIL, 1957

Elemental Composition (Per Cent)	Elemental Composition (Per Cent) and Yield						
	N	P	K	Ca	Mg	Na	Yield
				Field Experiment[1]			
N	1.000	.292*	.597**	.815**	.473**	.743**	-.785**
P		1.000	.130	.003	.373**	.442**	-.022
K			1.000	.465**	.032	.273*	-.528**
Ca				1.000	.371**	.654**	-.757**
Mg					1.000	.535**	-.321*
Na						1.000	-.568**
				Greenhouse Experiment[2]			
N	1.000	.524**	-.159	.758**	.565**	.232	-.428**
P		1.000	-.169	.229	.444**	.201	.094
K			1.000	.035	-.249	-.516**	.048
Ca				1.000	.539**	.328*	-.375**
Mg					1.000	.436**	-.367**
Na						1.000	-.240

[1]Chemical composition of entire wheat plants and yield in bushels per acre.

[2]Chemical composition of wheat straw and total dry matter yield in grams per pot.

* Significant at 5 per cent probability level.
** Significant at 1 per cent probability level.

per cent magnesium and sodium. Potassium concentrations in the wheat plants were significantly related to the calcium and sodium concentrations. The calcium contents were directly related to the magnesium and sodium contents of the plants. A positive relationship existed between magnesium and sodium concentrations.

In this experiment, grain yields were negatively correlated with the nitrogen, potassium, calcium, magnesium, and sodium contents of the plants.

The inter-relationships between the mineral elements of the grain are shown in Table VI. Statistically significant correlations were found between nitrogen, phosphorus, potassium, calcium,and magnesium concentrations. The phosphorus content of the grain was significantly correlated with the potassium and magnesium levels. Potassium was directly related to the calcium and magnesium concentrations. Other significant relationships existed between sodium and calcium and magnesium levels.

Grain yields were negatively correlated with the nitrogen, potassium, calcium, and magnesium contents of the grain. These correlations are similar to those found between yield and plant composition except for sodium.

Greenhouse Experiment

Similar relationships existed in the greenhouse as were found in the field except that in the greenhouse there was no association between nitrogen and the potassium

TABLE VI

SIMPLE CORRELATION COEFFICIENTS BETWEEN THE CHEMICAL COMPOSITION OF WHEAT GRAIN OR SPIKES AND YIELD ON SIMS LOAM SOIL,1957

Elemental Composition (Per Cent)	Elemental Composition (Per Cent) and Yield						
	N	P	K	Ca	Mg	Na	Yield
Field Experiment[1]							
N	1.000	.437**	.691**	.303*	.564**	.031	-.733**
P		1.000	.561**	.137	.645**	.189	-.149
K			1.000	.515**	.610**	.118	-.713**
Ca				1.000	.156	.380**	-.489**
Mg					1.000	.278*	-.464**
Na						1.000	-.110
Greenhouse Experiment[2]							
N	1.000	.015	.278*	.462**	.449**	.319*	-.277*
P		1.000	.225	.057	.439**	.010	. 017
K			1.000	.641**	.514**	.231	-.325**
Ca				1.000	.661**	.551**	-.401**
Mg					1.000	.515**	-.381**
Na						1.000	- .176

[1]Chemical composition of wheat grain and yield in bushels per acre.

[2]Chemical composition of wheat spikes and total dry matter yield in grams per pot.

* Significant at 5 per cent level.
** Significant at 1 per cent level.

and sodium concentrations in the wheat straw, Table V. Also phosphorus--sodium, potassium--calcium, and sodium versus yield were not related. The corrlation between potassium and sodium in the greenhouse was negative.

In regard to the composition of the spikes, essentially the same relationships were found in the greenhouse as in the field with grain. The deviations occurred between nitrogen and phosphorus, nitrogen and sodium, phosphorus and potassium, and calcium and magnesium.

Predicting Wheat Yields from Applied Nutrients, Soil Tests, and Plant Chemical Composition

Statistical estimates of yield for field and greenhouse conditions were obtained from the other studied variables and are reported in Table XXII (appendix).

Similar regression equations, as have been described for beans, were fitted to the data to predict wheat yields. These equations were calculated to examine yield responses to plant nutrients and changes in plant materials chemical composition. In the field experiment chemical composition of whole wheat plant at dough stage and chemical composition of wheat grain at maturity were selected for correlating with grain yield. In the greenhouse experiment the chemical composition of wheat heads and wheat straw were used for estimating the total dry matter yield per pot.

The data presented in equations IX to XII predict wheat grain yield from the information obtained under field conditions.

Equation IX*--(Wheat Grown in the Field)

$$\hat{Y}_w = 65.585924 - \underset{(.026205)}{.020645}\, N_a - \underset{(.541827)}{.629843}\sqrt{N_a} + \underset{(.115189)}{.054492}\, P_a$$

$$- \underset{(3.094066)}{1.148138}\sqrt{P_a} - \underset{(.015265)}{.013608}\, P_{st} + \underset{(.432564)}{.559842}\sqrt{P_{st}}$$

$$+ \underset{(.252346)}{.216625}\, K_a - \underset{(5.654858)}{4.922067}\sqrt{K_a} - \underset{(.026997)}{.020744}\, K_{st}$$

$$+ \underset{(.527309)}{.553044}\sqrt{K_{st}}$$

$R^2 = .630 \quad R = .794^{**} \quad \bar{R}^2 = .546 \quad \bar{R} = .739 \quad S = 4.929$

The adjusted coefficient of multiple correlation for the above equation was .739. The coefficient of multiple determination indicated that about 55 per cent of the variance in yield was associated with variance in applied plant nutrients and available phosphorus and potassium soil tests. Estimated parameters, however, were not significant.

Equation X--(Wheat Grown in the Field)

$$\hat{Y}_w = 21.945636 - \underset{(.022390)}{.044367}\, N_a - \underset{(.431878)}{.105390}\sqrt{N_a} - \underset{(.020667)}{.019817}\, P_t$$

$$+ \underset{(.816290)}{1.005870}\sqrt{P_t} - \underset{(.048075)}{.013479}\, K_t + \underset{(1.518967)}{.514991}\sqrt{K_t}$$

$R^2 = .611 \quad R = .782^{**} \quad \bar{R}^2 = .563 \quad \bar{R} = .750 \quad S = 4.836$

The adjusted coefficient of multiple correlation for the above equation was .750. The adjusted coefficient of

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* Equations IX to XVI No. of observations = 56

multiple determination indicated that 56 per cent of the variance in wheat grain yield was associated with the variance in applied nitrogen and total plant nutrients, phosphorus and potassium, in the soil. None of the parameters were significant. This indicates that factors other than plant nutrients greatly affected yield.

The third equation was calculated by using wheat plant chemical composition variables as shown in equation XI.

Equation XI--(Wheat Grown in the Field)

$$\hat{Y}_W = 50.299513 - \underset{(4.737430)}{13.080244}\,N_p + \underset{(15.354962)}{26.967753}\,P_p - \underset{(2.530989)}{2.476908}\,K_p - \underset{(27.234239)}{35.638291}\,Ca_p - \underset{(18.844625)}{2.406188}\,Mg_p - \underset{(43.640723)}{22.180475}\,Na_p$$

$R^2 = .685 \quad R = .828^{**} \quad \bar{R}^2 = .646 \quad \bar{R} = .804 \quad S = 4.350$

The adjusted coefficient of multiple correlation was .804. The adjusted coefficient of multiple determination indicated that 65 per cent of the variance in wheat grain yield was associated with the variance in the chemical composition of wheat plants. The estimated coefficient for the nitrogen content of the wheat plants was significant at one per cent probability level. Other coefficients were not significant.

Regression equation XII shows the relationship between plant nutrients, plant chemical composition, and yield.

Equation XII--(Wheat Grown in the Field)

$$\hat{Y}_w = 36.489618 - \underset{(.026466)}{.009231}\,N_a - \underset{(.463679)}{.026502}\sqrt{N_a}$$

$$- \underset{(.022397)}{.019255}\,P_t + \underset{(.988623)}{.930458}\sqrt{P_t} - \underset{(.048541)}{.024480}\,K_t$$

$$+ \underset{(1.551302)}{.741507}\sqrt{K_t} - \underset{(6.731452)}{9.724553}\,N_p + \underset{(31.455334)}{5.820376}\,P_p$$

$$- \underset{(3.338893)}{2.667633}\,K_p - \underset{(36.317976)}{20.284454}\,Ca_p - \underset{(20.309529)}{.436149}\,Mg_p$$

$$- \underset{(51.083215)}{42.384684}\,Na_p$$

$R^2 = .704 \quad R = .839^{**} \quad \bar{R}^2 = .619 \quad \bar{R} = .787 \quad S = 4.511$

The adjusted coefficients of multiple correlation and multiple determination for equation XII are .787 and .619, respectively. None of the coefficients were statistically significant at the 5 per cent level of significance.

The wheat grain chemical composition variables were selected for the study of relationships with grain yield under field conditions. The functional relationships between plant nutrients, wheat grain chemical composition, and yield are reported in equations XIII to XVI. Deviations in taking four plot samples occurred between whole plant samples and grain samples. Therefore, regression equations predicting grain yield were calculated taking into consideration this fact.

Equation XIII--(Wheat Grown in the Field)

$$\hat{Y}_w = 80.814437 - \underset{(.025061)}{.020049}\, N_a - \underset{(.526072)}{.630177}\sqrt{N_a} + \underset{(.114367)}{.060719}\, P_a$$

$$- \underset{(3.089308)}{1.378305}\sqrt{P_a} - \underset{(.014512)}{.019819}\, P_{st} + \underset{(.421049)}{.708470}\sqrt{P_{st}}$$

$$+ \underset{(.277362)}{.377768}\, K_a - \underset{(6.001649)}{7.949440}\sqrt{K_a} - \underset{(.027829)}{.028112}\, K_{st}$$

$$+ \underset{(.526612)}{.645511}\sqrt{K_{st}}$$

$R^2 = .648 \quad R = .805^{**} \quad \bar{R}^2 = .568 \quad \bar{R} = .754 \quad S = 4.853$

None of the parameters were statistically significant. However, the adjusted coefficient of multiple correlation was .754. The coefficient of multiple determination was .568 which indicated that 57 per cent of the variance in wheat yield was associated with variance either as an aggregate effect of all plant nutrients or due to their effect on some other variables in plant environment which may be more directly associated with yield.

The regression equation XIV was recalculated using applied nitrogen, total plant nutrients, phosphorus and potassium, in the soil and their square roots as independent variables.

Equation XIV--(Wheat Grown in the Field)

$$\hat{Y}_w = 21.570946 - \underset{(.022510)}{.044264}\, N_a - \underset{(.435821)}{.102961}\sqrt{N_a} - \underset{(.023076)}{.018061}\, P_t$$

$$+ \underset{(.893224)}{.912465}\sqrt{P_t} - \underset{(.051191)}{.018364}\, K_t + \underset{(1.613256)}{.695600}\sqrt{K_t}$$

$R^2 = .620 \quad R = .788^{**} \quad \bar{R}^2 = .573 \quad \bar{R} = .757 \quad S = 4.829$

The adjusted coefficient of multiple correlation for the regression equation was .757. The adjusted coefficient of multiple determination explained association of about 57 per cent of the variance in yield with the regression. None of the individual coefficients were significant. This also suggested that some other variables in plant environment might be more directly associated with yield variance.

The formulation of equation XV takes into account wheat grain chemical composition. Subscript "g" identifies per cent of respective elements in wheat grain.

<u>Equation XV</u>--(Wheat Grown in the Field)

$$\hat{Y}_w = 68.943197 - \underset{(\ 2.580389)}{11.736458}\, N_g + \underset{(17.597240)}{81.891912}\, P_g$$

$$- \underset{(17.927257)}{63.563296}\, K_g - \underset{(55.440532)}{75.612562}\, Ca_g - \underset{(31.260157)}{51.695358}\, Mg_g$$

$$- \underset{(188.078658)}{55.921103}\, Na_g$$

$R^2 = .758 \quad R = .870^{**} \quad \bar{R}^2 = .727 \quad \bar{R} = .853 \quad S = 3.855$

Coefficients of the variables nitrogen, phosphorus, and potassium in the above regression equation were highly significant. The adjusted coefficient of multiple correlation was .853. The adjusted coefficient of multiple determination was .727. It indicated that 73 per cent of variance in yield was associated with the variance in the wheat grain chemical composition.

Equation XVI takes into account plant nutrients and wheat grain chemical composition in predicting wheat grain yield for the field experiment.

Equation XVI--(Wheat Grown in the Field)

$$\hat{Y}_w = 10.277672 - \underset{(.021656)}{.021521} N_a + \underset{(.379599)}{.134981} \sqrt{N_a} - \underset{(.023490)}{.003201} P_t$$

$$- \underset{(.982682)}{.021638} \sqrt{P_t} - \underset{(.042600)}{.026838} K_t + \underset{(1.355114)}{1.011741} \sqrt{K_t}$$

$$- \underset{(4.978627)}{9.760702} N_g + \underset{(36.155299)}{91.771846} P_g - \underset{(21.453402)}{58.083452} K_g$$

$$- \underset{(57.720817)}{77.255549} Ca_g - \underset{(38.004797)}{52.458019} Mg_g - \underset{(211.669488)}{106.267114} Na_g$$

$R^2 = .784 \quad R = .885^{**} \quad \bar{R}^2 = .722 \quad \bar{R} = .850 \quad S = 3.893$

The adjusted coefficients of multiple correlation and multiple determination were .850 and .722, respectively. It indicated that 72 per cent of the variability in wheat grain yields was accounted for by its association with soil nutrient content and the chemical composition of wheat grain. The coefficients of the per cent phosphorus and per cent potassium in wheat grain were significant. None of the other coefficients were statistically significant.

The following six equations pertain to the data collected in the greenhouse. Data were collected separately on the chemical composition of wheat heads and straw. Total dry matter per pot was used as a yield measure.

Regression equations XVII to XX explain association of yield variance due to soil nutrient content and chemical composition of the wheat heads.

Equation XVII*-(Wheat Grown in the Greenhouse)

$$\hat{Y}_{dm} = 16.957419 - \underset{(.020176)}{.045684} N_a + \underset{(.574258)}{1.001907} \sqrt{N_a} - \underset{(.021004)}{.008500} P_a$$
$$+ \underset{(.932622)}{.414524} \sqrt{P_a} + \underset{(.011343)}{.006539} P_{st} - \underset{(.479998)}{.165882} \sqrt{P_{st}}$$
$$- \underset{(.029686)}{.003805} K_a + \underset{(1.092112)}{.201147} \sqrt{K_a} - \underset{(.022182)}{.021253} K_{st}$$
$$+ \underset{(.567454)}{.624632} \sqrt{K_{st}}$$

$R^2 = .282 \quad R = .531 \quad \bar{R}^2 = .119 \quad \bar{R} = .345 \quad S = 7.215$

The estimated parameter for applied nitrogen was statistically significant at five per cent probability level. All other coefficients were not significant. The adjusted coefficient of multiple correlation was .345. The coefficient of multiple determination was .119. This indicated that variance in the soil nutrient content failed to account for the variance in total dry matter yield under greenhouse conditions.

Equation XVIII-(Wheat Grown in the Greenhouse)

$$\hat{Y}_{dm} = 16.677 - \underset{(.017471)}{.051359} N_a + \underset{(.494575)}{1.166541} \sqrt{N_a} + \underset{(.009826)}{.004055} P_t$$
$$- \underset{(.576452)}{.111857} \sqrt{P_t} - \underset{(.017787)}{.019214} K_t + \underset{(.778636)}{.876390} \sqrt{K_t}$$

$R^2 = .272 \quad R = .521 \quad \bar{R}^2 = .181 \quad \bar{R} = .425 \quad S = 6.957$

The above statistical estimates indicated a poor association between the variance in soil nutrient content and yields. The coefficient of applied nitrogen was statistically significant at the one per cent probability level.

*Equations XVII to XXIII No. of observations = 55

The coefficient for the square root of applied nitrogen was statistically significant at the five per cent probability level. None of the other parameters were significant.

The regession equation XIX was calculated by using the chemical composition of the wheat heads. The subscript "h" denotes wheat heads.

Equation XIX--(Wheat Grown in the Greenhouse)

$$\hat{Y}_{dm} = 41.432550 - \underset{(5.798916)}{21.418869}\, N_h + \underset{(14.235884)}{18.576160}\, P_h$$

$$- \underset{(8.120407)}{4.635021}\, K_h - \underset{(51.210745)}{36.790553}\, Ca_h$$

$$- \underset{(37.124436)}{60.642034}\, Mg_h + \underset{(376.232718)}{312.536293}\, Na_h$$

$$R^2 = .229 \quad R = .478 \quad \bar{R}^2 = .132 \quad \bar{R} = .364 \quad S = 7.159$$

None of the estimated parameters are significant in the above equation, except for per cent nitrogen in the spikes.

A twelve variable regression equation was fitted to the data using information on soil nutrient content and chemical composition of wheat heads. The estimated coefficients for different variables are reported in equation XX.

Equation XX--(Wheat Grown in the Greenhouse)

$$\hat{Y}_{dm} = 58.435100 - \underset{(.018755)}{.040288}\, N_a + \underset{(.503303)}{1.167206}\sqrt{N_a} - \underset{(.009160)}{.001001}\, P_t$$

$$+ \underset{(.538241)}{.285515}\sqrt{P_t} - \underset{(.016880)}{.017251}\, K_t + \underset{(.737018)}{.780262}\sqrt{K_t}$$

$$- \underset{(6.197947)}{8.826469}\, N_h - \underset{(16.691822)}{17.139331}\, P_h - \underset{(8.335017)}{7.453543}\, K_h$$

$$- \underset{(60.049799)}{39.228357}\, Ca_h - \underset{(40.311510)}{18.563752}\, Mg_h - \underset{(360.871390)}{49.157054}\, Na_h$$

$$R^2 = .469 \quad R = .685 \quad \bar{R}^2 = .317 \quad \bar{R} = .563 \quad S = 6.352$$

The adjusted coefficient of multiple correlation for the equation was .563. The adjusted coefficient of multiple determination indicated that about 32 per cent of the variability in yield was accounted for by its association with soil nutrient content and chemical composition of the wheat heads.

The chemical composition of wheat straw from the greenhouse experiment was determined. The regression relationships between total dry matter yield and chemical composition of straw are reported in equation XXI. The subscript "s" with each element denotes its percentage in straw.

Equation XXI--(Wheat Grown in the Greenhouse)

$$\hat{Y}_{dm} = 60.770145 \underset{(4.716534)}{- 17.768251} N_s \underset{(13.875246)}{+ 57.762863} P_s$$

$$\underset{(4.003365)}{- 5.811148} K_s \underset{(2.675266)}{+ 4.697292} Ca_s \underset{(13.393807)}{- 27.117847} Mg_s$$

$$\underset{(87.375245)}{- 154.775073} Na_s$$

$$R^2 = .432 \quad R = .657^{**} \quad \bar{R}^2 = .361 \quad \bar{R} = .601 \quad S = 6.142$$

The adjusted coefficient of multiple correlation for the above regression equation was .601. The adjusted coefficient of multiple determination indicated that 36 per cent of the variance in yield was associated with variance in the chemical composition of wheat straw. The coefficients of the nitrogen and phosphorus contents of wheat straw were significant at the one per cent level of probability. The coefficient for magnesium was significant at the five per cent level of probability. All other coefficients were not statistically significant.

Equation XXII shows the regression relationships for certain variables and yield.

Equation XXII--(Wheat Grown in the Greenhouse)

$$\begin{aligned}\hat{Y}_{dm} = {} & 53.392765 - \underset{(.017993)}{.026737}\,N_a + \underset{(\ .412988)}{1.010456}\sqrt{N_a} - \underset{(.008400)}{.004323}\,P_t \\ & + \underset{(.493215)}{.369409}\sqrt{P_t} - \underset{(.016060)}{.010435}\,K_t + \underset{(.782844)}{.566704}\sqrt{K_t} \\ & - \underset{(\ 5.178470)}{17.150224}\,N_s + \underset{(22.464206)}{31.763533}\,P_s - \underset{(6.371650)}{9.369652}\,K_s \\ & + \underset{(4.094158)}{.615970}\,Ca_s - \underset{(12.132208)}{23.180420}\,Mg_s - \underset{(88.997432)}{147.564011}\,Na_s\end{aligned}$$

$R^2 = .612 \quad R = .782^{**} \quad \bar{R}^2 = .501 \quad \bar{R} = .708 \quad S = 5.426$

Consideration of all studied variables improved the predicting power of the regression equation. The adjusted coefficient of multiple correlation was .708. The adjusted coefficient of multiple determination accounted for 50 per cent of the variance in yield with this regression.

The coefficient of per cent nitrogen in wheat straw was statistically significant at the one per cent probability level. The coefficient of the square root of applied nitrogen was significant at the five per cent probability level.

A significant regression coefficient would indicate a high association. However, it is noted that the magnitude and statistical significance of a variable in regression analysis is subject to the effects of other associated variables. This affects the reliability of the testing procedure for an individual variable. Factors related to plant growth, but not statistically significant, should not be dropped from a regression analysis unless previous knowledge and experience justifies it.

One can not expect to account for 100 per cent of the variance in yield unless all of the factors that influence plant growth can be controlled. This is usually far from possible. In addition to the studied variables, there were other factors such as temperature, wind velocity, rainfall, relative humidity, et cetera, which may have influenced the development of the plants and caused variations in yield. The highly possible effects of such variables should not be ignored. Experimental errors, as may unfortunately occur in chemical analysis as well as in taking representative samples, et cetera, are also important factors. In these experiments changes in the chemical composition of the plants accounted for a great part of the variance in yield. The nitrogen, potassium, calcium, magnesium, and sodium levels in the bean plants accounted for as high as 66 per cent of the yield variance. The variance in the nitrogen, phosphorus, and potassium levels in wheat grain accounted for as high as 73 per cent of the yield variance.

SUMMARY

Field, greenhouse, and laboratory studies were carried out to examine relationships between applied nutrients, the chemical composition of the plant materials, and the yield of field beans and wheat. Nitrogen, phosphate, and potash fertilizers were used at different rates and combinations on a Sims loam soil. The plant portions sampled for chemical analysis were: (1) whole plants of beans and wheat and wheat grain grown in the field, and (2) whole bean plants, wheat straw, and wheat heads grown in the greenhouse.

1. Under field conditions, nitrogen increased the grain yields of beans, but decreased the yields of wheat. Phosphate and potash fertilizers did not significantly affect the grain yields of these crops.

2. In the greenhouse experiments nitrogen applications significantly increased the total dry matter yields in beans but had no effect on the wheat crop. Applied phosphate significantly increased the wheat yields but did not affect the bean yields. Yieldwise, no response was observed from the use of potash fertilizer on either crop.

3. In both crops a slight but insignificant decrease occurred in the nitrogen concentrations with low levels of applied nitrogen but a significant increase resulted with subsequent additions of fertilizer.

Applications of phosphate, and potash fertilizers increased the concentrations of the fertilizer elements in plant and seed materials of the crops grown under both field and greenhouse conditions.

4. Nitrogen additions were directly associated with the magnesium contents in wheat plants and grain of the crop grown in the field as well as in the straw and spikes of wheat grown in the greenhouse. No such relationship existed in the bean plants. Nitrogen levels were associated with the percentages of calcium in the bean plants, in the wheat plants, in the wheat grain, and in the wheat spikes as well as in the straw.

5. Applied phosphorus was positively related to the potassium contents of bean plants grown in the field and in the greenhouse but no such relationship was present in the wheat.

6. Potash fertilization depressed the magnesium uptake in the bean plants grown in both field and greenhouse experiments. No such association existed in wheat.

7. Nitrogen concentrations were positively associated with the calcium and magnesium levels of bean plants, and phosphorus, calcium, and magnesium levels of wheat plants and grain grown in the field, and the wheat straw grown in the greenhouse.

8. Potassium levels in the bean plants grown in the greenhouse were negatively correlated with the magnesium levels. The wheat did not exhibit such an association.

9. In both field and greenhouse experiments, the phosphorus contents of the wheat were associated positively

with magnesium contents in respective tissues. This was not the case with beans.

10. Potassium levels in wheat grain grown in the field and wheat spikes grown in the greenhouse were directly related to the calcium and magnesium contents.

11. The magnesium and sodium levels increased as the calcium levels increased in wheat plants and wheat straw grown both under field and greenhouse conditions. In the grain grown in the field there was a close relationship between calcium and sodium.

12. Magnesium concentrations in the wheat plants and grain were positively associated with the sodium contents. This was not the case for beans.

13. The estimated parameters in the regression analysis revealed that the yield increased with increases in nitrogen, phosphorus, and calcium concentrations in the bean plants grown in the field. Increase in sodium levels decreased yields.

14. The regression coefficients for nitrogen and potassium levels of wheat grain were negatively related to yield. Increases in the phosphorus levels occurred as grain yields increased.

15. Practical application of field experimental data suggested that the chemical composition of plants or grain is more reliable a basis for predicting crop yields than are applied nutrients or soil test values.

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APPENDIX

TABLE VII

THE EFFECT OF APPLIED NUTRIENTS ON THE pH AND AVAILABLE PLANT NUTRIENTS IN THE SOIL UNDER FIELD (F) AND GREENHOUSE (G) CONDITIONS DURING 1956-1957

Levels[1] of Applied Nutrients			Plot No.	pH			Spurway Reserve Soil Test					
				1956	1957		F&G 1956		F 1957		G 1957	
N	P_2O_5	K_2O		F&G	F	G	P	K	P	K	P	K
0	0	0	768	6.5	6.6	6.1	96	132	90	96	88	76
0	0	0	843	7.1	7.2	7.0	144	272	132	165	209	206
0	0	2	650	6.5	6.5	6.2	120	120	132	110	187	82
0	0	3	781	6.8	6.8	6.5	78	132	66	103	77	76
0	0	5	811	6.5	6.5	6.2	102	176	90	154	77	206
1	0	0	731	7.0	6.9	6.5	96	144	84	69	110	76
4	0	0	760	6.9	7.0	6.0	53	112	48	55	44	34
6	0	0	685	6.2	5.9	5.0	96	116	96	96	297	89
0	1	0	675	6.8	6.6	6.2	108	112	84	82	198	76
1	1	1	776	6.4	6.5	5.8	132	156	108	103	110	48
2	1	1	719	6.5	6.8	6.0	90	132	108	76	110	82
3	1	1	833	6.5	6.4	5.9	78	156	90	89	110	89
4	1	3	644	6.5	6.6	5.7	150	156	102	103	187	165
5	1	4	615	6.7	6.8	5.1	180	132	102	89	374	137
5	1	6	655	6.3	6.2	5.2	96	272	102	165	242	576
6	1	5	716	6.5	6.4	5.1	114	224	108	96	110	534
2	2	2	635	6.6	6.9	5.2	138	144	132	117	726	137
2	2	5	748	6.6	6.4	5.8	84	144	120	165	187	398
3	2	2	689	6.5	6.6	6.0	132	132	132	89	209	96
4	2	3	754	7.1	7.2	6.7	114	104	96	82	143	151
5	2	2	624	6.5	6.5	4.6	114	112	132	96	319	82
5	2	6	691	6.5	6.3	5.3	138	280	126	165	187	414
6	2	3	740	6.4	6.2	5.0	120	176	96	110	165	275
6	2	5	684	6.3	6.3	5.0	132	200	132	96	330	220
0	3	0	640	6.8	6.8	---	180	112	180	117	---	---
1	3	2	849	7.2	7.0	6.8	102	132	78	76	275	110
1	3	6	755	7.2	7.1	6.5	114	132	96	130	198	254
2	3	1	772	6.3	6.4	5.7	156	132	144	110	594	82
2	3	4	646	6.6	6.5	5.9	204	200	120	124	462	275
3	3	1	625	6.1	6.3	5.5	144	156	138	117	396	89
3	3	3	854	6.6	---	5.1	132	156	---	---	143	62
5	3	5	666	6.8	6.7	5.3	144	192	126	124	440	343
1	4	4	832	6.4	6.7	5.9	288	144	84	96	924	316
3	4	4	779	6.5	6.7	5.6	144	84	120	103	374	110
4	4	2	708	6.6	6.6	5.3	192	120	132	76	682	124
4	4	4	679	6.4	6.3	5.5	150	156	138	103	198	130
4	4	5	622	6.6	6.6	5.2	150	120	162	82	583	268

TABLE VII (continued)

Levels[1] of Applied Nutrients N	P_2O_5	K_2O	Plot No.	pH 1956 F&G	pH 1957 F	pH 1957 G	Spurway Reserve Soil Test F&G 1956 P	F&G 1956 K	F 1957 P	F 1957 K	G 1957 P	G 1957 K
5	4	3	703	6.6	6.7	5.2	144	120	168	103	242	89
6	4	3	741	6.5	6.2	4.9	220	156	138	96	858	103
6	4	4	688	6.2	6.3	5.4	288	224	150	117	462	172
1	5	4	656	6.5	6.5	5.8	192	156	132	124	550	165
2	5	2	758	7.1	7.2	6.2	204	120	198	96	418	69
3	5	2	828	7.0	7.1	6.0	324	200	192	89	627	110
3	5	5	673	6.6	6.6	6.0	240	156	150	110	715	288
4	5	1	714	6.6	6.6	5.4	192	168	174	61	462	89
5	5	3	616	6.6	6.7	5.0	288	144	156	117	792	151
5	5	5	649	6.5	6.3	5.3	252	200	192	137	660	240
6	5	4	850	6.9	6.6	5.1	288	192	138	69	286	178
0	6	0	658	6.3	6.4	5.7	252	120	198	124	1188	69
1	6	1	633	6.4	6.5	5.3	240	144	330	117	660	89
1	6	6	701	6.4	6.6	5.6	204	224	234	206	1320	990
2	6	1	637	6.7	6.7	5.7	216	132	360	124	682	89
2	6	6	670	6.3	6.5	5.7	120	200	192	151	462	618
3	6	6	820	6.9	6.9	6.0	300	256	174	144	1320	741
4	6	6	823	6.7	6.6	5.5	300	296	174	178	495	288
6	6	6	793	6.9	6.6	5.4	252	256	138	158	1518	700

Key:

Nutrient	Level and Rate* in Pounds per Acre 0	1	2	3	4	5	6
N:	0	20	40	80	160	240	320
P_2O_5:	0	40	80	160	320	480	640
K_2O :	0	20	40	80	160	240	320

*Double fertilizer rate in greenhouse experiments than field experiments as listed above.

TABLE VIII

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE pH AND AVAILABLE PLANT NUTRIENTS IN THE SOIL UNDER FIELD (F) AND GREENHOUSE (G) CONDITIONS DURING 1956-1957

Levels of Applied Nutrients[1]			pH			Spurway Reserve Soil Test					
			1956	1957		F&G 1956		F 1957		G 1957	
N	P_2O_5	K_2O	F&G	F	G	P	K	P	K	P	K
V*	0	V*	6.7	6.7	6.2	98	---	92	---	136	---
"	1	"	6.5	6.5	5.6	119	---	101	---	180	---
"	2	"	6.6	6.6	5.5	122	---	121	---	283	---
"	3	"	6.7	6.7	5.8	147	---	126	---	358	---
"	4	"	6.5	6.5	5.4	197	---	137	---	540	---
"	5	"	6.7	6.7	5.6	248	---	167	---	564	---
"	6	"	6.6	6.6	5.6	236	---	225	---	956	---
V*	V*	0	6.7	6.7	6.1	---	140	---	101	---	90
"	"	1	6.4	6.5	5.7	---	147	---	100	---	82
"	"	2	6.8	6.8	5.8	---	135	---	94	---	101
"	"	3	6.4	6.6	5.5	---	143	---	102	---	134
"	"	4	6.5	6.6	5.5	---	161	---	104	---	185
"	"	5	6.6	6.5	5.5	---	177	---	122	---	312
"	"	6	6.7	6.6	5.7	---	240	---	162	---	573
0	V*	V*	6.7	6.7	6.3	---	---	---	---	---	---
1	"	"	6.7	6.7	6.0	---	---	---	---	---	---
2	"	"	6.6	6.7	5.8	---	---	---	---	---	---
3	"	"	6.6	6.7	5.8	---	---	---	---	---	---
4	"	"	6.7	6.7	5.7	---	---	---	---	---	---
5	"	"	6.6	6.5	5.1	---	---	---	---	---	---
6	"	"	6.5	6.3	5.1	---	---	---	---	---	---

*V--Varies

[1]See page 70 for key.

[2]Average of two determinations.

TABLE IX

THE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF BEAN PLANTS AND YIELD IN THE FIELD EXPERIMENT, 1956

Levels of Applied Nutrients[1]			Plot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Bu/ A
0	0	0	768	2.70	.253	1.38	1.68	.618	.008	16.3
0	0	0	843	2.88	.315	2.50	1.13	.550	.005	24.6
0	0	2	650	2.43	.265	1.84	1.29	.608	.007	16.4
0	0	3	781	2.97	.248	1.93	1.78	.660	.007	18.1
0	1	0	675	2.63	.300	1.38	1.61	.660	.006	20.0
0	6	0	658	2.19	.305	1.34	1.69	.695	.007	23.1
1	0	0	731	2.73	.265	1.15	1.38	.660	.006	18.3
1	1	1	776	2.86	.260	1.76	1.88	.660	.006	21.4
1	3	2	849	2.76	.371	2.20	1.78	.718	.007	27.0
1	3	6	755	2.72	.325	2.83	1.73	.538	.007	27.4
1	4	4	832	2.59	.413	3.08	1.59	.728	.007	23.8
1	5	4	656	2.03	.340	2.18	1.50	.565	.006	20.7
1	6	1	633	2.46	.379	1.66	1.80	.593	.007	23.7
1	6	6	701	2.28	.331	2.71	1.23	.463	.008	14.3
2	1	1	719	2.12	.216	1.26	1.08	.343	.009	8.4
2	2	2	635	2.53	.290	1.56	2.06	.508	.007	22.4
2	2	5	748	2.18	.253	2.25	1.55	.415	.006	17.2
2	3	1	772	2.60	.275	1.86	1.55	.253	.006	23.6
2	3	4	646	2.20	.300	2.03	1.50	.350	.011	20.2
2	5	2	758	1.78	.290	1.31	1.15	.538	.008	7.2
2	6	1	673	2.38	.360	1.86	1.93	.508	.007	23.8
2	6	6	670	3.04	.413	3.34	1.46	.508	.006	26.0
3	1	1	833	3.17	.325	2.25	1.68	.415	.010	30.1
3	2	2	689	2.72	.253	1.61	2.13	.750	.007	22.7
3	3	1	625	2.57	.265	1.38	1.68	.565	.006	17.9
3	3	3	854	3.00	.328	2.60	2.03	.640	.008	33.0
3	4	4	779	3.04	.390	3.14	2.36	.660	.007	32.7
3	5	2	828	2.94	.460	2.50	1.90	.800	.007	23.0
3	5	5	673	2.45	.360	2.55	1.55	.550	.007	31.5
3	6	6	820	2.76	.408	3.34	1.88	.443	.007	29.4
4	0	0	760	3.37	.260	1.24	2.45	1.035	.009	19.1
4	1	3	644	2.32	.253	1.68	1.93	.443	.007	25.5
4	2	3	754	2.88	.281	2.18	2.25	.825	.006	31.6
4	4	2	708	2.95	.331	1.41	2.55	1.020	.006	28.0
4	4	4	679	3.44	.379	3.14	1.44	.675	.007	33.4
4	4	5	622	2.70	.315	2.18	2.06	.540	.006	28.0
4	5	1	714	3.10	.350	1.31	3.36	.795	.008	27.8

TABLE IX (Continued)

Levels of Applied Nutrients[1]			Plot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Bu/ A
4	6	6	823	3.20	.424	3.50	2.04	.500	.007	28.4
5	1	4	615	2.88	.210	1.76	1.73	.425	.012	20.1
5	1	6	655	2.94	.216	2.63	1.99	.470	.007	22.8
5	2	2	624	2.92	.300	1.66	2.41	.743	.007	22.6
5	3	5	666	2.78	.290	2.43	1.71	.508	.007	18.2
5	4	3	703	2.95	.275	1.66	2.31	.728	.007	25.0
5	5	3	616	2.86	.390	1.61	2.50	.645	.007	30.0
5	5	5	649	2.69	.374	2.68	1.72	.415	.007	24.4
6	0	0	685	3.21	.210	1.50	2.11	.795	.008	21.1
6	1	5	716	3.32	.223	2.58	2.06	.315	.007	30.6
6	2	3	740	3.42	.306	2.09	2.36	.755	.006	34.0
6	2	5	684	3.28	.255	3.30	2.36	.550	.012	27.2
6	4	3	741	3.38	.379	2.50	2.00	.675	.006	32.5
6	4	4	688	2.86	.281	2.06	2.36	.665	.007	23.1
6	5	4	850	3.39	.315	2.38	2.63	.825	.008	29.7
6	6	6	793	3.49	.473	3.45	1.68	.608	.007	34.5

[1]See page 70 for key.

[2]Average of two determinations.

TABLE X

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF BEAN PLANTS AND YIELD IN THE FIELD EXPERIMENT, 1956

Levels of Applied Nutrients[1]			Elemental Composition of Bean Plants (Per Cent)						Yield
N	P_2O_5	K_2O	N	P	K	Ca	Mg	Na	Bu/ A
0	Varies	Varies	2.54	.287	1.69	1.52	.611	.006	19.5
1	"	"	2.55	.325	2.07	1.61	.588	.007	21.8
2	"	"	2.35	.300	1.93	1.53	.416	.007	18.6
3	"	"	2.83	.349	2.42	1.90	.603	.007	27.5
4	"	"	3.00	.339	2.19	2.07	.729	.007	28.3
5	"	"	2.86	.294	2.06	2.05	.562	.008	23.3
6	"	"	3.29	.305	2.48	2.20	.649	.007	29.1
Varies	0	Varies	2.82	.259	1.65	1.69	.704	.007	19.1
"	1	"	2.78	.253	1.91	1.74	.466	.008	22.4
"	2	"	2.85	.276	2.09	2.16	.649	.007	25.4
"	3	"	2.61	.306	2.10	1.68	.507	.007	23.2
"	4	"	2.99	.338	2.30	2.16	.709	.006	29.0
"	5	"	2.66	.360	2.06	1.91	.642	.007	24.3
"	6	"	2.73	.392	2.70	1.70	.561	.007	26.2
Varies	Varies	0	2.75	.279	1.49	1.69	.662	.007	20.1
"	"	1	2.66	.311	1.67	1.74	.517	.007	21.1
"	"	2	2.63	.313	1.91	1.87	.713	.007	22.4
"	"	3	2.97	.307	2.03	2.14	.671	.007	28.7
"	"	4	2.80	.316	2.38	1.93	.595	.008	25.7
"	"	5	2.71	.295	2.56	1.86	.470	.007	25.3
"	"	6	2.55	.370	3.11	1.71	.501	.007	26.1

[1] See page 70 for key.

TABLE XI

THE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF BEAN PLANTS AND TOTAL DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT, 1956

Levels of Applied Nutrients[1]			Pot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Gms/Pot
0	0	0	768	3.17	.340	2.27	2.34	.780	.008	18
0	0	0	843	3.14	.425	2.82	1.08	.620	.009	26
0	0	2	650	3.10	.385	2.42	1.85	.643	.008	20
0	0	3	781	2.69	.300	2.21	2.48	.588	.006	20
0	0	5	811	2.59	.353	3.10	1.77	.468	.008	24
0	1	0	675	3.29	.385	1.28	1.81	.670	.010	24
0	6	0	658	3.35	.525	2.56	2.31	.620	.008	23
1	0	0	731	2.99	.480	1.62	2.09	.843	.009	26
1	1	1	776	3.28	.370	1.98	2.34	.758	.008	24
1	3	2	849	3.15	.463	2.33	2.26	.870	.009	26
1	3	6	755	2.62	.333	3.52	3.14	.538	.010	26
1	4	4	832	2.42	.443	3.10	1.38	.643	.006	26
1	5	4	656	2.48	.430	3.28	2.27	.400	.009	34
1	6	1	633	3.31	.550	2.33	1.19	.788	.009	24
1	6	6	701	2.94	.508	3.78	3.14	.525	.009	24
2	1	1	719	2.55	.308	1.32	1.80	.705	.008	30
2	2	2	635	3.09	.368	1.65	1.30	.595	.007	36
2	2	5	748	2.98	.380	3.13	2.34	.620	.009	28
2	3	1	772	3.35	.430	1.85	2.51	.880	.007	32
2	3	4	646	3.02	.370	3.22	1.23	.370	.009	32
2	5	2	758	3.22	.520	2.12	2.27	.893	.010	32
2	6	1	637	3.26	.565	1.80	1.53	.880	.008	30
2	6	6	670	2.97	.470	3.76	2.83	.330	.008	30
3	1	1	833	3.52	.338	2.27	2.48	.833	.008	30
3	3	1	625	3.53	.365	2.33	2.24	.788	.011	33
3	3	3	854	2.80	.340	2.93	2.34	.688	.010	28
3	4	4	779	3.33	.463	2.18	1.79	.628	.006	32
3	5	2	828	3.43	.498	2.45	2.26	.805	.008	28
3	5	5	673	3.43	.508	3.52	2.89	.415	.009	30
3	6	6	820	3.55	.583	3.46	2.51	.738	.008	24
4	0	0	760	3.65	.250	1.42	3.57	.880	.008	32
4	1	3	644	3.52	.345	2.80	2.00	.483	.009	27
4	2	3	754	3.46	.480	2.56	3.01	.820	.007	26
4	4	2	708	3.35	.433	2.09	2.95	.798	.010	32
4	4	4	679	3.41	.458	3.80	3.08	.633	.009	31
4	4	5	622	3.40	.405	3.10	2.09	.458	.013	33
4	5	1	714	3.56	.525	2.43	3.51	.820	.012	28

TABLE XI (Continued)

Levels of Applied Nutrients[1]			Pot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Gms/Pot
4	6	6	823	3.38	.493	3.62	3.18	.630	.008	24
5	1	4	615	3.36	.343	2.99	2.96	.605	.008	36
5	1	6	655	3.53	.308	3.17	4.08	.420	.011	24
5	2	2	624	3.66	.340	2.33	2.94	.680	.011	38
5	3	5	666	3.68	.483	3.04	1.90	.370	.009	30
5	4	3	703	3.62	.455	2.30	3.39	.680	.012	27
5	5	3	616	3.57	.493	2.69	3.35	.660	.010	32
5	5	5	649	3.59	.505	3.07	3.23	.620	.010	34
6	0	0	685	3.62	.220	1.93	2.34	.680	.012	34
6	1	5	716	3.60	.345	2.80	3.98	.688	.009	24
6	2	3	740	3.76	.333	2.75	2.39	.855	.009	24
6	2	5	684	3.53	.345	2.93	4.70	.600	.009	28
6	4	3	741	3.77	.490	2.33	3.45	.733	.010	26
6	5	4	850	3.60	.508	2.69	3.48	.688	.011	30
6	6	6	793	3.56	.470	2.69	3.33	.733	.007	32

[1]See page 70 for key.

[2]Average of two determinations.

TABLE XII

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF BEAN PLANTS AND TOTAL DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT, 1956

Levels of Applied Nutrients[1]			Elemental Composition of Bean Plants (Per Cent)						Yield Gms/ Pot
N	P_2O_5	K_2O	N	P	K	Ca	Mg	Na	
0	Varies	Varies	3.05	.388	2.38	1.95	.627	.008	22.1
1	"	"	2.90	.431	2.74	2.37	.670	.009	26.3
2	"	"	3.06	.426	2.36	2.26	.659	.008	31.3
3	"	"	3.38	.442	2.73	2.36	.699	.009	29.3
4	"	"	3.47	.409	2.60	2.92	.690	.010	29.1
5	"	"	3.55	.403	2.84	3.15	.583	.010	31.6
6	"	"	3.58	.380	2.57	3.16	.684	.010	28.8
Varies	0	Varies	3.12	.328	2.22	2.19	.688	.008	25.0
"	1	"	3.33	.343	2.33	2.68	.645	.009	27.4
"	2	"	3.41	.346	2.64	2.87	.681	.009	30.0
"	3	"	3.16	.398	2.75	2.23	.643	.009	29.6
"	4	"	3.30	.434	2.55	2.47	.634	.010	29.9
"	5	"	3.36	.498	2.78	2.96	.663	.010	31.0
"	6	"	3.29	.520	3.00	2.59	.655	.008	26.4
Varies	Varies	0	3.32	.357	1.99	2.22	.728	.009	26.1
"	"	1	3.30	.431	2.04	2.29	.806	.009	28.9
"	"	2	3.29	.429	2.20	2.26	.755	.009	30.3
"	"	3	3.40	.389	2.57	2.80	.688	.009	26.3
"	"	4	3.09	.418	2.84	2.28	.558	.009	31.6
"	"	5	3.35	.415	3.09	2.86	.530	.009	28.9
"	"	6	3.24	.433	3.39	3.20	.563	.009	26.3

[1]See page 70 for key.

TABLE XIII

STATISTICAL ESTIMATES OF BEAN YIELD FROM SIGNIFICANT RELATIONSHIPS OF INDIVIDUAL VARIABLES WITH YIELD, 1956

Field Experiment

I. $\hat{Y}_b = f$ (applied N)

$\hat{Y}_b = 21.274 + .023237 \ X$

$r = .434 \qquad S = 6.066 \qquad \sigma b = .006842$

II. $\hat{Y}_b = f$ (Per cent N in plant tissue)

$\hat{Y}_b = -4.108 + 10.129199 \ X$

$r = .657 \qquad S = 6.066 \qquad \sigma b = 1.627550$

III. $\hat{Y}_b = f$ (Per cent P in plant tissue)

$\hat{Y}_b = 9.409 + 47.045952 \ X$

$r = .497 \qquad S = 5.364 \qquad \sigma b = 11.489788$

IV. $\hat{Y}_b = f$ (Per cent K in plant tissue)

$\hat{Y}_b = 13.650 + 4.912526 \ X$

$r = .530 \qquad S = 5.243 \qquad \sigma b = 1.099805$

V. $\hat{Y}_b = f$ (Per cent Ca in plant tissue)

$\hat{Y}_b = 11.516 + 6.747881 \ X$

$r = .483 \qquad S = 5.414 \qquad \sigma b = 1.711249$

Greenhouse Experiment

VI. $\hat{Y}_{dm} = f$ (applied N)

$\hat{Y}_{dm} = 26.868 + .005998 \ X$

$r = .304 \qquad S = 4.237 \qquad \sigma b = .002654$

TABLE XIV

THE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT PLANTS AND YIELD IN THE FIELD EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Plot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Bu/ A
0	0	0	768	1.19	.170	1.69	.138	.133	.036	26.1
0	0	0	843	0.80	.185	1.35	.075	.119	.010	40.9
0	0	2	637	0.85	.240	1.39	.090	.117	.018	40.0
0	0	3	781	1.02	.163	1.24	.105	.114	.031	31.6
0	0	5	811	1.05	.175	1.69	.103	.123	.020	31.9
0	1	0	675	0.82	.208	1.18	.100	.131	.020	34.8
0	3	0	641	1.05	.288	1.91	.072	.148	.021	37.8
0	6	0	658	1.17	.285	1.61	.075	.148	.028	32.2
1	0	0	731	0.96	.190	1.23	.090	.135	.024	25.8
1	1	1	776	1.22	.180	1.54	.128	.172	.054	33.0
1	3	2	849	0.99	.220	1.30	.098	.156	.028	44.5
1	3	6	755	0.94	.200	1.61	.100	.158	.014	35.5
1	4	4	832	0.77	.240	1.41	.085	.125	.014	43.3
1	5	4	656	1.09	.290	1.63	.078	.118	.026	37.1
1	6	1	633	1.11	.335	1.50	.082	.134	.029	34.5
1	6	6	701	0.67	.215	1.15	.058	.126	.017	45.8
2	1	1	719	0.76	.200	1.24	.075	.105	.014	36.0
2	2	2	635	0.98	.200	1.21	.095	.161	.022	37.7
2	2	5	748	1.06	.208	1.76	.075	.126	.020	29.6
2	3	1	772	1.01	.235	1.44	.127	.151	.033	35.2
2	3	4	647	1.23	.225	1.76	.088	.131	.022	34.5
2	5	2	758	0.92	.243	1.46	.090	.162	.040	39.7
2	6	1	638	1.10	.275	1.53	.058	.103	.021	39.4
2	6	6	670	0.91	.268	1.53	.065	.110	.013	36.3
3	1	1	833	1.38	.243	1.21	.123	.170	.029	46.2
3	2	2	689	1.21	.208	1.30	.133	.172	.030	27.9
3	3	1	625	1.34	.235	1.41	.133	.201	.077	21.8
3	3	3	854	1.45	.220	1.79	.145	.180	.041	34.2
3	4	4	779	1.13	.255	1.21	.095	.161	.033	36.2
3	5	2	828	0.92	.253	1.53	.110	.077	.024	40.3
3	5	5	673	0.98	.278	1.04	.078	.135	.017	36.4
3	6	6	820	0.93	.255	1.61	.085	.126	.015	34.0
4	0	0	760	1.45	.170	1.21	.178	.174	.045	21.9
4	1	3	645	1.41	.205	2.10	.160	.152	.040	24.2
4	2	3	754	1.42	.185	1.65	.190	.188	.044	26.4
4	4	2	708	1.42	.273	1.32	.165	.145	.085	24.3
4	4	4	679	1.64	.285	1.39	.133	.186	.050	27.3

TABLE XIV (Continued)

Levels of Applied Nutrients[1]			Plot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Bu/ A
4	4	5	622	1.39	.285	1.78	.138	.180	.046	28.1
4	5	1	714	1.53	.318	1.54	.185	.233	.128	29.4
4	6	6	823	1.34	.280	1.98	.138	.193	.047	27.2
5	1	4	615	1.60	.218	1.91	.163	.167	.058	24.4
5	1	6	655	1.54	.183	2.14	.140	.175	.040	25.2
5	2	2	624	1.61	.280	1.46	.188	.211	.047	19.6
5	2	6	691	1.55	.205	2.11	.158	.045	.047	26.9
5	3	5	666	1.48	.230	2.04	.113	.161	.041	22.0
5	4	3	703	1.59	.310	1.58	.178	.133	.091	20.7
5	5	3	616	1.60	.335	1.89	.138	.215	.076	24.4
5	5	6	650	1.67	.300	2.11	.133	.168	.077	24.8
6	0	0	685	1.65	.178	1.83	.185	.193	.037	19.4
6	1	5	716	1.56	.170	2.33	.222	.050	.043	23.3
6	2	3	740	1.53	.220	1.76	.207	.162	.041	21.9
6	2	5	684	1.55	.193	2.01	.207	.138	.051	22.9
6	4	3	741	1.60	.333	1.51	.180	.236	.081	28.6
6	4	4	688	1.63	.300	1.94	.148	.117	.061	21.3
6	5	4	850	1.85	.335	1.98	.163	.217	.087	27.8
6	6	6	793	1.49	.333	2.35	.180	.208	.038	24.2

[1]See page 70 for key.

[2]Average of two determinations.

TABLE XV

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT PLANTS AND YIELD IN THE FIELD EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Elemental Composition of Wheat Plants (Per Cent)						Yield
N	P_2O_5	K_2O	N	P	K	Ca	Mg	Na	Bu/ A
0	Varies	Varies	1.03	.214	1.51	.095	.129	.023	34.4
1	"	"	0.97	.234	1.42	.089	.141	.026	37.4
2	"	"	0.96	.232	1.49	.084	.131	.023	36.1
3	"	"	1.19	.243	1.44	.113	.153	.034	34.6
4	"	"	1.45	.250	1.62	.171	.181	.061	26.1
5	"	"	1.58	.258	1.90	.151	.172	.059	23.6
6	"	"	1.61	.258	1.96	.186	.165	.054	23.7
Varies	0	Varies	1.15	.184	1.46	.120	.139	.027	29.7
"	1	"	1.29	.201	1.70	.139	.140	.037	30.9
"	2	"	1.36	.212	1.66	.156	.150	.037	26.6
"	3	"	1.19	.232	1.66	.109	.161	.034	33.2
"	4	"	1.40	.285	1.52	.140	.160	.057	28.7
"	5	"	1.32	.294	1.70	.122	.166	.059	32.6
"	6	"	1.06	.281	1.66	.093	.144	.026	34.2
Varies	Varies	0	1.14	.209	1.50	.114	.148	.027	29.9
"	"	1	1.15	.253	1.42	.114	.159	.048	34.4
"	"	2	1.14	.239	1.37	.121	.150	.037	34.3
"	"	3	1.45	.246	1.69	.163	.173	.055	26.6
"	"	4	1.37	.268	1.65	.119	.153	.044	30.2
"	"	5	1.30	.220	1.87	.133	.130	.034	27.7
"	"	6	1.23	.249	1.95	.117	.145	.034	31.1

[1]See page 70 for key.

TABLE XVI

THE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT GRAIN AND YIELD IN THE FIELD EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Plot No.	Elemental Composition[2] (Per Cent)						Yield
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	Bu/ A
0	0	0	768	2.08	.383	.531	.052	.213	.020	26.1
0	0	0	843	1.85	.442	.475	.031	.206	.018	40.9
0	0	2	637	1.79	.455	.531	.029	.199	.020	40.0
0	0	3	781	2.02	.370	.475	.018	.188	.018	31.6
0	0	5	811	2.02	.393	.519	.018	.203	.018	31.9
0	1	0	675	1.64	.438	.506	.023	.213	.019	34.8
0	4	0	649	1.78	.472	.531	.022	.196	.017	41.5
0	6	0	658	1.90	.468	.556	.031	.226	.019	32.2
1	0	0	731	1.79	.373	.475	.035	.165	.021	25.8
1	1	1	776	2.12	.400	.500	.018	.213	.017	33.0
1	3	2	849	1.88	.468	.475	.015	.216	.021	44.5
1	3	6	755	2.01	.430	.531	.034	.175	.018	35.5
1	4	4	832	1.87	.450	.506	.034	.206	.021	43.3
1	5	4	656	1.84	.468	.543	.029	.173	.018	37.1
1	6	1	633	1.84	.468	.550	.034	.223	.020	34.5
1	6	6	701	1.59	.442	.531	.021	.183	.017	45.8
2	1	1	719	1.88	.403	.531	.025	.169	.019	36.0
2	2	2	635	1.80	.420	.519	.023	.199	.018	37.7
2	2	5	748	2.16	.487	.595	.031	.248	.024	29.6
2	3	1	772	1.89	.450	.543	.024	.234	.018	35.2
2	3	4	758	1.84	.447	.531	.021	.183	.018	39.7
2	5	2	670	1.79	.408	.506	.015	.144	.018	36.3
3	1	1	833	2.25	.442	.495	.013	.209	.019	46.2
3	2	2	689	2.09	.455	.588	.023	.234	.021	27.9
3	2	6	646	2.03	.462	.575	.033	.199	.020	34.7
3	3	1	625	1.99	.425	.595	.072	.223	.025	21.8
3	3	3	854	2.41	.438	.495	.029	.216	.031	34.2
3	4	4	779	2.21	.487	.556	.018	.230	.019	36.2
3	5	2	828	2.00	.472	.495	.018	.216	.018	40.3
3	5	5	673	1.88	.500	.540	.050	.216	.038	36.4
3	6	4	640	1.90	.475	.575	.072	.193	.020	34.8
3	6	6	820	2.14	.465	.495	.018	.216	.020	34.0
4	0	0	760	2.21	.338	.513	.029	.175	.020	21.9
4	2	3	754	2.44	.425	.550	.042	.186	.018	26.4
4	4	2	708	2.29	.505	.608	.029	.230	.017	24.3
4	4	4	679	2.35	.495	.625	.038	.248	.020	27.3
4	4	5	622	2.25	.487	.625	.042	.230	.022	28.1

TABLE XVI (Continued)

Levels of Applied Nutrients[1] N	P_2O_5	K_2O	Plot No.	Elemental Composition[2] (Per Cent) N	P	K	Ca	Mg	Na	Yield Bu/ A
4	5	1	714	2.24	.508	.608	.035	.248	.021	29.4
4	6	6	823	2.56	.505	.563	.029	.241	.018	27.2
5	1	4	615	2.32	.462	.625	.034	.226	.021	24.4
5	1	6	655	2.43	.458	.595	.050	.254	.030	25.2
5	2	2	624	2.34	.458	.613	.042	.230	.019	19.6
5	2	6	691	2.37	.438	.625	.044	.209	.018	26.9
5	3	5	666	2.34	.495	.563	.041	.230	.020	22.0
5	4	3	703	2.34	.482	.608	.029	.241	.018	20.7
5	5	3	616	2.33	.505	.625	.038	.213	.019	25.1
5	5	6	650	2.46	.523	.608	.035	.241	.020	24.8
6	0	0	685	2.43	.455	.681	.042	.274	.020	19.4
6	1	2	644	2.50	.465	.625	.034	.226	.019	21.3
6	1	5	716	2.69	.468	.629	.055	.203	.016	23.3
6	2	3	740	2.65	.468	.595	.034	.234	.023	21.9
6	2	5	684	2.69	.468	.656	.050	.216	.019	22.9
6	4	3	741	2.62	.505	.588	.049	.213	.020	28.6
6	4	4	688	2.46	.522	.681	.035	.250	.021	21.3
6	5	4	850	2.51	.523	.585	.023	.261	.020	27.8
6	6	6	793	2.63	.522	.588	.025	.248	.021	24.2

[1]See page 70 for key.

[2]Average of two determinations.

TABLE XVII

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT GRAIN AND YIELD IN THE FIELD EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Elemental Composition of Wheat Grain (Per Cent)						Yield
N	P_2O_5	K_2O	N	P	K	Ca	Mg	Na	Bu/ A
0	Varies	Varies	1.88	.429	.516	.028	.206	.019	34.9
1	"	"	1.87	.438	.514	.028	.194	.019	37.4
2	"	"	1.89	.436	.538	.023	.196	.019	35.8
3	"	"	2.09	.462	.541	.035	.215	.023	34.7
4	"	"	2.33	.481	.585	.035	.220	.019	26.4
5	"	"	2.36	.478	.595	.039	.231	.021	23.6
6	"	"	2.58	.489	.625	.039	.236	.020	23.4
Varies	0	Varies	2.02	.401	.525	.032	.203	.020	29.1
"	1	"	2.23	.442	.563	.032	.214	.020	31.4
"	2	"	2.29	.454	.580	.036	.217	.020	27.5
"	3	"	2.09	.451	.534	.036	.216	.022	32.2
"	4	"	2.29	.487	.592	.033	.227	.019	30.1
"	5	"	2.01	.493	.567	.031	.219	.022	32.2
"	6	"	2.04	.469	.558	.031	.209	.019	33.6
Varies	Varies	0	1.96	.421	.534	.033	.210	.019	30.3
"	"	1	2.03	.442	.546	.032	.216	.020	33.7
"	"	2	2.06	.461	.554	.026	.215	.019	32.8
"	"	3	2.40	.456	.562	.034	.213	.021	26.9
"	"	4	2.23	.486	.587	.036	.223	.020	31.5
"	"	5	2.29	.471	.590	.041	.221	.022	27.4
"	"	6	2.20	.465	.562	.030	.211	.020	31.5

[1]See page 70 for key.

TABLE XVIII

THE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT STRAW AND TOTAL DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Pot No.	Elemental Composition[2] (Per Cent)						Yield Gms/ Pot
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	
0	0	0	768	1.14	.153	1.32	0.33	.125	.021	33.3
0	0	0	843	0.88	.053	1.81	0.38	.088	.015	28.6
0	0	2	650	0.95	.063	1.75	0.43	.150	.021	27.8
0	0	3	781	1.05	.115	1.81	0.35	.200	.015	23.7
0	0	5	811	0.78	.046	1.96	0.55	.125	.030	27.9
0	1	0	675	1.26	.062	1.36	0.93	.300	.048	17.1
0	6	0	658	1.17	.203	1.06	0.58	.300	.061	29.9
1	0	0	731	1.03	.043	1.68	0.50	.175	.038	17.5
1	1	1	776	1.15	.083	1.61	0.55	.125	.025	28.3
1	3	2	849	1.07	.102	1.48	0.58	.275	.045	29.1
1	3	6	755	0.83	.028	2.09	1.08	.225	.045	23.4
1	4	4	832	0.94	.172	2.06	0.68	.250	.023	29.0
1	5	4	656	1.55	.213	1.56	1.30	.150	.045	26.4
1	6	1	633	1.42	.235	1.36	1.13	.250	.065	32.5
1	6	6	701	1.29	.228	1.88	0.63	.175	.018	32.1
2	1	1	719	1.09	.055	1.61	0.60	.225	.035	26.6
2	2	2	635	1.63	.093	1.64	0.63	.150	.025	25.2
2	2	5	748	1.05	.083	2.09	0.65	.225	.020	32.7
2	3	1	772	1.04	.080	1.35	0.90	.200	.033	30.1
2	3	4	646	0.99	.055	1.84	0.75	.113	.036	33.5
2	5	2	758	1.17	.180	1.33	0.68	.200	.053	31.6
2	6	1	637	1.43	.288	1.09	0.43	.400	.050	31.1
2	6	6	670	1.46	.273	2.07	0.68	.275	.021	35.6
3	1	1	833	1.31	.110	1.48	0.65	.175	.028	29.0
3	2	2	689	1.22	.055	1.58	1.18	.225	.050	23.5
3	3	1	625	1.40	.129	1.33	0.60	.225	.051	40.7
3	3	3	854	1.66	.140	1.75	1.05	.225	.013	35.7
3	4	4	779	1.26	.205	1.66	0.63	.200	.028	33.8
3	5	2	828	1.32	.236	1.54	0.60	.275	.021	32.1
3	5	5	673	1.45	.258	1.75	0.60	.150	.020	33.5
3	6	6	820	1.29	.180	1.23	1.02	.250	.025	32.1
4	0	0	760	1.40	.033	1.44	0.75	.113	.036	21.6
4	1	3	644	1.17	.048	1.68	0.93	.225	.025	33.0
4	2	3	754	1.26	.075	2.06	0.85	.225	.025	31.3
4	4	2	708	1.74	.195	1.06	1.55	.363	.058	21.2
4	4	4	679	2.08	.291	1.64	1.58	.338	.043	24.6
4	4	5	622	1.23	.148	1.78	1.20	.175	.023	51.0

TABLE XVIII (Continued)

Levels of Applied Nutrients[1]			Pot No.	Elemental Composition[2] (Per Cent)						Yield Gms/ Pot
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	
4	5	1	714	1.45	.270	1.56	0.88	.225	.025	34.8
4	6	6	823	1.57	.195	2.07	1.65	.225	.038	32.8
5	1	4	615	1.53	.178	1.56	1.63	.150	.044	33.0
5	1	6	655	1.29	.063	1.81	1.38	.200	.028	24.0
5	2	2	624	1.18	.039	1.42	1.50	.225	.036	45.2
5	2	6	691	1.53	.108	2.09	1.18	.125	.025	28.8
5	3	5	666	1.65	.180	1.69	1.95	.275	.045	20.6
5	4	3	703	1.54	.163	1.61	1.18	.300	.014	31.4
5	5	3	616	1.48	.175	1.44	2.20	.338	.043	33.2
5	5	5	649	1.39	.180	1.78	1.48	.150	.035	42.6
6	0	0	685	2.10	.050	1.54	2.03	.300	.021	11.2
6	1	5	716	1.66	.098	1.88	2.25	.250	.040	22.8
6	2	3	740	1.61	.071	1.81	1.65	.200	.025	24.1
6	2	5	684	2.42	.235	1.71	2.40	.425	.053	7.6
6	4	3	741	1.65	.205	1.61	1.55	.150	.023	24.3
6	4	4	688	2.31	.275	1.50	2.25	.300	.048	18.3
6	5	4	850	2.13	.224	1.54	2.60	.525	.043	17.3
6	6	6	793	1.51	.185	2.03	1.98	.338	.040	21.9

[1]See page 70 for key.

[2]Average of two determinations.

TABLE XIX

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT STRAW AND TOTAL DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Elemental Composition of Wheat Straw (Per Cent)						Yield
N	P_2O_5	K_2O	N	P	K	Ca	Mg	Na	Gms/Pot
0	Varies	Varies	1.03	.099	1.58	0.30	.184	.030	26.9
1	"	"	1.16	.138	1.71	0.80	.203	.038	27.3
2	"	"	1.23	.138	1.63	0.66	.224	.034	30.8
3	"	"	1.37	.164	1.66	0.79	.216	.029	32.6
4	"	"	1.49	.157	1.66	1.17	.236	.034	31.3
5	"	"	1.45	.136	1.68	1.56	.220	.034	32.6
6	"	"	1.92	.168	1.70	2.09	.311	.036	18.4
Varies	0	Varies	1.17	.070	1.66	0.66	.160	.025	24.0
"	1	"	1.31	.087	1.62	1.12	.206	.034	26.7
"	2	"	1.49	.095	1.80	1.25	.225	.032	27.3
"	3	"	1.23	.102	1.65	0.99	.220	.038	30.4
"	4	"	1.59	.207	1.61	1.34	.259	.032	29.2
"	5	"	1.49	.217	1.56	1.29	.252	.036	31.4
"	6	"	1.39	.223	1.72	1.01	.264	.040	31.0
Varies	Varies	0	1.28	.085	1.46	0.78	.200	.034	22.7
"	"	1	1.29	.156	1.42	0.72	.228	.039	31.6
"	"	2	1.29	.120	1.48	0.88	.233	.039	29.5
"	"	3	1.43	.124	1.72	1.22	.233	.023	32.1
"	"	4	1.60	.202	1.67	1.43	.253	.039	27.0
"	"	5	1.45	.154	1.83	1.38	.222	.033	29.8
"	"	6	1.35	.158	2.16	1.20	.227	.030	28.8

[1] See page 70 for key.

TABLE XX

THE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT SPIKES AND TOTAL DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Pot No.	Elemental Composition[2] (Per Cent)						Yield Gms/ Pot
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	
0	0	0	768	2.62	.613	0.76	.021	.241	.007	33.3
0	0	0	843	2.77	.515	0.70	.017	.203	.014	28.6
0	0	2	650	2.89	.535	0.70	.019	.203	.008	27.8
0	0	3	781	2.91	.560	0.86	.013	.245	.012	23.7
0	0	5	811	2.72	.528	0.79	.016	.196	.012	27.9
0	1	0	675	2.76	.503	0.79	.036	.226	.009	17.1
0	6	0	658	2.64	.608	0.69	.024	.229	.015	29.9
1	0	0	731	2.71	.560	0.96	.025	.193	.009	17.5
1	1	1	776	3.02	.520	0.70	.017	.245	.013	28.3
1	3	2	849	2.97	.540	0.84	.020	.241	.010	29.1
1	3	6	755	2.96	.495	1.19	.033	.257	.017	23.4
1	4	4	832	3.01	.648	0.84	.021	.233	.012	29.0
1	5	4	656	3.01	.625	0.76	.042	.224	.010	26.4
1	6	1	633	3.05	.630	0.82	.048	.266	.012	32.5
1	6	6	701	2.92	.648	0.86	.020	.196	.012	32.1
2	1	1	719	3.06	.452	0.60	.020	.162	.013	26.6
2	2	2	635	3.46	.625	0.87	.030	.264	.012	25.2
2	2	5	748	3.12	.488	0.86	.020	.169	.010	32.7
2	3	1	772	2.89	.583	0.90	.021	.255	.013	30.1
2	3	4	646	2.98	.515	0.62	.025	.194	.014	33.5
2	5	2	758	2.88	.648	0.98	.022	.266	.012	31.6
2	6	1	637	2.93	.643	0.56	.017	.249	.014	31.1
2	6	6	670	2.98	.674	1.02	.032	.234	.014	35.6
3	1	1	833	2.99	.525	0.79	.021	.243	.013	29.0
3	2	2	689	2.97	.490	1.08	.059	.206	.010	23.5
3	3	1	625	2.95	.555	0.79	.037	.223	.016	40.7
3	3	3	854	3.20	.538	0.82	.056	.273	.009	35.7
3	4	4	779	3.08	.718	0.86	.020	.275	.010	33.8
3	5	2	828	2.85	.718	0.79	.022	.264	.014	32.1
3	5	5	673	2.93	.625	0.84	.032	.216	.010	33.5
3	6	6	820	2.98	.653	0.96	.025	.250	.014	32.1
4	0	0	760	3.31	.500	0.86	.025	.249	.012	21.6
4	1	3	644	3.02	.430	0.76	.050	.186	.012	33.0
4	2	3	754	3.02	.490	0.82	.024	.165	.010	31.3
4	4	2	708	3.05	.620	0.82	.072	.268	.014	21.2
4	4	4	679	3.52	.795	1.23	.123	.364	.017	24.6
4	4	5	622	2.91	.568	0.70	.028	.211	.012	51.0

TABLE XX (Continued)

Levels of Applied Nutrients[1]			Pot No.	Elemental Composition[2] (Per Cent)						Yield Gms/ Pot
N	P_2O_5	K_2O		N	P	K	Ca	Mg	Na	
4	5	1	714	2.88	.678	0.99	.028	.240	.009	34.8
4	6	6	823	2.96	.648	1.10	.057	.261	.017	32.8
5	1	4	615	2.92	.578	0.58	.032	.241	.018	33.0
5	1	6	655	3.05	.420	0.96	.056	.189	.017	24.0
5	2	2	624	2.92	.410	0.84	.086	.218	.017	45.2
5	2	6	691	3.10	.580	0.99	.047	.203	.008	28.8
5	3	5	666	3.01	.568	0.96	.071	.250	.012	20.6
5	4	3	703	2.99	.695	0.79	.046	.202	.011	31.4
5	5	3	616	3.07	.595	1.13	.119	.298	.021	33.2
5	5	5	649	3.04	.588	1.10	.065	.245	.011	42.6
6	0	0	685	3.66	.435	1.05	.135	.373	.019	11.2
6	1	5	716	3.17	.500	1.09	.104	.226	.015	22.8
6	2	3	740	3.04	.515	0.88	.056	.216	.010	24.1
6	2	5	684	3.01	.695	1.09	.135	.329	.017	7.6
6	4	3	741	3.02	.663	1.13	.058	.229	.008	24.3
6	4	4	688	3.41	.695	0.88	.056	.279	.020	18.3
6	5	4	850	3.15	.600	1.08	.123	.343	.018	17.3
6	6	6	793	2.71	.630	1.25	.100	.313	.014	21.9

[1]See page 70 for key.

[2]Average of two determinations.

TABLE XXI

THE AVERAGE EFFECT OF APPLIED NUTRIENTS ON THE CHEMICAL COMPOSITION OF WHEAT HEADS AND TOTAL DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT, 1957

Levels of Applied Nutrients[1]			Elemental Composition of Wheat Heads (Per Cent)						Yield Gms/ Pot
N	P_2O_5	K_2O	N	P	K	Ca	Mg	Na	
0	Varies	Varies	2.76	.552	0.75	.021	.220	.011	26.9
1	"	"	2.96	.583	0.87	.028	.232	.012	27.3
2	"	"	3.04	.579	0.80	.023	.224	.013	30.8
3	"	"	2.99	.603	0.86	.034	.244	.012	32.6
4	"	"	3.08	.591	0.91	.051	.243	.013	31.3
5	"	"	3.01	.556	0.92	.065	.231	.014	32.6
6	"	"	3.15	.592	1.06	.096	.294	.015	18.4
Varies	0	Varies	2.95	.531	0.83	.034	.232	.011	24.0
"	1	"	3.00	.491	0.78	.042	.215	.014	26.7
"	2	"	3.08	.537	0.93	.057	.221	.012	27.3
"	3	"	2.99	.542	0.87	.038	.242	.011	30.4
"	4	"	3.12	.675	0.91	.053	.269	.013	29.2
"	5	"	2.98	.635	0.96	.057	.262	.013	31.4
"	6	"	2.90	.642	0.91	.040	.250	.014	31.0
Varies	Varies	0	2.92	.532	0.83	.040	.255	.012	22.7
"	"	1	2.97	.580	0.77	.026	.235	.013	31.6
"	"	2	3.00	.573	0.86	.041	.241	.012	29.5
"	"	3	3.04	.561	0.90	.053	.220	.012	32.1
"	"	4	3.16	.647	0.86	.055	.281	.015	27.0
"	"	5	2.99	.570	0.93	.059	.230	.012	29.8
"	"	6	2.96	.594	1.04	.046	.238	.014	28.8

[1]See page 70 for key.

TABLE XXII

STATISTICAL ESTIMATES OF WHEAT YIELD FROM SIGNIFICANT RELATIONSHIPS OF INDIVIDUAL VARIABLES WITH YIELD, 1957

Field Experiment

I. Wheat Grain Yield = f (Applied N)

$$\hat{Y}_W = 36.577 - .046887 \; X$$

$r = -.733 \qquad S = 5.024 \qquad \sigma b = .005984$

II. Wheat Grain Yield = f (Per cent N in plant tissue)

$$\hat{Y}_W = 54.516 - 19.006696 \; X$$

$r = -.785 \qquad S = 4.569 \qquad \sigma b = 2.058730$

III. Wheat Grain Yield = f (Per Cent K in plant tissue)

$$\hat{Y}_W = 49.977 - 11.926070 \; X$$

$r = -.528 \qquad S = 6.270 \qquad \sigma b = 2.636346$

IV. Wheat Grain Yield = f (Per cent Ca in plant tissue)

$$\hat{Y}_W = 46.644 - 126.503459 \; X$$

$r = -.757 \qquad S = 4.825 \qquad \sigma b = 15.009647$

V. Wheat Grain Yield = f (Per cent Mg in plant tissue)

$$\hat{Y}_W = 39.596024 - 58.454718 \; X$$

$r = -.321 \qquad S = 6.991 \qquad \sigma b = 23.723785$

VI. Wheat Grain Yield = f (Per cent Na in plant tissue)

$$\hat{Y}_W = 37.590 - 171.280277 \; X$$

$r = .568 \qquad S = 6.072 \qquad \sigma b = 34.070$

TABLE XXII (continued)

VII. Wheat Grain Yield = f (Per cent N in wheat grain)

$$\hat{Y}_w = 70.295 - 18.39812 \; X$$

$r = -.733 \qquad s = 5.069 \qquad \sigma_b = 2.345563$

VIII. Wheat Grain Yield = f (Per cent K in wheat grain)

$$\hat{Y}_w = 86.001 - 98.227579 \; X$$

$r = -.713 \qquad s = 5.222 \qquad \sigma_b = 13.258243$

IX. Wheat Grain Yield = f (Per cent Ca in wheat grain)

$$\hat{Y}_w = 39.804 - 277.108434 \; X$$

$r = -.489 \qquad s = 6.501 \qquad \sigma_b = 68.105788$

X. Wheat Grain Yield = f (Per cent Mg in wheat grain)

$$\hat{Y}_w = 58.558 - 129.360465 \; X$$

$r = -.464 \qquad s = 6.600 \qquad \sigma_b = 33.937964$

<u>Greenhouse Experiment</u>

Total dry matter yield per pot in grams is a measure of yield.

XI. $\hat{Y}_{dm}$ = f (Per cent K in wheat heads)

$$\hat{Y}_{dm} = 41.887 - 15.111940 \; X$$

$r = -.325 \qquad s = 7.337 \qquad \sigma_b = 6.045746$

XII. $\hat{Y}_{dm}$ = f (Per cent Ca in wheat heads)

$$\hat{Y}_{dm} = 32.788 - 92.335666 \; X$$

$r = -.401 \qquad s = 7.106 \qquad \sigma_b = 28.939898$

TABLE XXII (Continued)

XIII. $\hat{Y}_{dm} = f$ (Per cent Mg in wheat heads)

$\hat{Y}_{dm} = 44.182491 - 64.962406\ X$

$r = -.381 \qquad S = 7.173 \qquad \sigma_b = 21.656551$

XIV. $\hat{Y}_{dm} = f$ (Per cent N in wheat straw)

$\hat{Y}_{dm} = 41.460 - 9.329518\ X$

$r = -.428 \qquad S = 7.010 \qquad \sigma_b = 2.703258$

XV. $\hat{Y}_{dm} = f$ (Per cent Ca in wheat straw)

$\hat{Y}_{dm} = 33.808 - 4.812180\ X$

$r = -.375 \qquad S = 7.193 \qquad \sigma_b = 1.636215$

XVI. $\hat{Y}_{dm} = f$ (Per cent Mg in wheat straw)

$\hat{Y}_{dm} = 36.087 - 33.008356\ X$

$r = -.367 \qquad S = 7.215 \qquad \sigma_b = 11.481685$

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