DIFFERENTIAL RESPONSE AMONG BEAN VARIETIES (*Phaseolus vulgaris* L.) TO NITROGEN AND PHOSPHORUS

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ABSTRACT

DIFFERENTIAL RESPONSE AMONG BEAN VARIETIES
(Phaseolus vulgaris L.) TO NITROGEN
AND PHOSPHORUS

By

Wayne Leroy Haag

The response of several varieties of Phaseolus vulgaris L. to nitrogen and phosphorus was investigated under field and greenhouse conditions.

Much variability in response was found for yield and the yield components. Response to fertilizer could not be predicted from values obtained prior to application.

Different patterns of yield component response occurred among the varieties. Varieties responded differentially to P, but not to N. The simple effect of N was much greater than the simple effect of P.

Phosphorus levels were varied in a hydroponics experiment. The P, K, Ca, and Mg concentrations in the plant tissue were determined. The P treatments affected the P and K concentrations. Varietal and plant part differences existed for all of the elements observed.

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TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

Figure | Page

Figure | Page

INTRODUCTION

Application of mineral nutrients to the soil has long been an accepted means of increasing crop yield. Agronomists accept, not always with confirmatory evidence, that beans (*Phaseolus vulgaris* L.) respond inefficiently to mineral fertilization.

Symbiosis with *Rhizobium* may have rendered this legume independent of mineral nitrate levels in the soil. Hence, there has been no strong selection, natural or intentional, for genes that render the species more efficient in nitrate uptake and utilization. It has been suggested that these legumes evolved under conditions of an ancient agriculture both in Central America and the Orient on soils relatively low in available nutrients. As a consequence, the species may never have developed the ability to respond to high fertility conditions. The genetic reasoning would be that genes leading to greater response did not have an opportunity of being preferentially selected, because they may have required a high fertility environment in which to express themselves. This environment may not have existed under primitive agricultural conditions.

Another argument states that under conditions of exhausted fertility, the plants most likely to be chosen for domestication, would be those most efficient in utilizing nutrients at low concentrations. Thus, those chosen for domestication might utilize nutrients inefficiently under conditions of nutrient abundance.

In the future it may become desirable to select types of *Phaseolus vulgaris* L. for their response capacity, therefore, the variability present in the species must be known. Varietal responses to applied nutrients have been investigated more in some species than in others. Yield responses in a large number of representative varieties of *Phaseolus vulgaris* have not been investigated, hence, total range of response for the species is not known. When the range and variability are known, a better idea of the potential of the species may be obtained. The allegation that the species responds inefficiently to mineral fertilization can then be more critically evaluated.

If varieties respond differentially to fertilization, there must be certain physiological and/or morphological characters, under genetic control, which differentiate the varieties. Differences with respect to mineral nutrition may exist for absorption, translocation, and/or utilization, thus providing a physiological basis for differentiating the genotypes.

Differential response may occur for some elements, but not for others. In understanding differential response, it must be known to which elements or combinations of elements the varieties are responding differentially.

From a management viewpoint, agriculturalists must be aware of varietal differences for optimal levels of nutrients, as well as possible differences in tolerance when nutrient levels are either above or below the optimum for a given variety.

The objective of this research was to answer the following questions concerning the mineral nutrition of beans:

1. How do increments of nitrogen (N) and phosphorus (P) affect yield (W) and the yield components, i.e., number of pods per plant (X), number of seeds per pod (Y), and seed weight (Z)?
2. Are there varietal differences in response to applied N and P for W, X, Y, and Z?
3. Can response to an increment of N and P be predicted from the values obtained under conditions of low N and P?
4. Does N, P, or the NxP interaction promote differential response?
5. Do varieties differ in tolerance of sub, or supra-optimal levels of N and P?
6. Do improved and unimproved varieties show distinctly different responses to W, X, Y, and Z?
7. Do varieties differ in concentrating P and other elements in their tissue at different levels of P in the nutrient medium?

LITERATURE REVIEW

Before considering differential response, it is of interest to consider the general nutritional requirements of *Phaseolus vulgaris* L. The requirements are based on the elemental composition of the plant tissue. Work by several authors has been reviewed and condensed by Fassbender (1967). He found N, P_2O_5, K_2O, S, Ca, and Mg to be present in the following approximate proportions: 1:0.22:0.70:0.027:0.30: 0.053.

Brief mention will also be made concerning fertilization practices with emphasis on the major elements N, P, and K. In a literature review by Martini and Pinchinat (1967), the data indicated that nitrogen response was highly variable, phosphorus response generally significant, and potassium response generally non-significant.

Although beans have a very high nitrogen content, their requirement for applied nitrogen would be expected to be quite low due to the nitrogen made available through the symbiotic relationship with *Rhizobium*. In spite of this, the bean and other legumes may respond to nitrogen. Nodule bacteria do not fix adequate nitrogen for the short season legumes, according to Sprague (1964). Allos and Bartholomew (1959), found that soybeans, alfalfa, sweet clover, Ladino clover, and birdsfoot trefoil, responded to the addition of inorganic nitrogen both in increased growth and nitrogen uptake. They found that each species supplied by fixation only one-half to three-fourths the total nitrogen used by the plant.

Generally, beans responded well to phosphorus fertilization. This appears to be a consequence of the low level of available phosphorus found in many soils, according to Martini and Pinchinat (1967).

Fassbender (1967) pointed out that in some isolated instances response to applied potassium had been observed in Latin America. In the United States responses to applied potassium are more frequent.

In a fertilizer program it may be necessary to consider differential responses of varieties. The information available regarding differential response of Phaseolus vulgaris L. to nitrogen and phosphorus is meager. Literature dealing with varietal differences in response to these elements in other agronomic crops may be useful in understanding Phaseolus vulgaris L. responses.

Working with wheat, Lamb and Salter (1936), showed a differential yield response between two varieties. Woodward (1966) demonstrated that dwarf wheat varieties were capable of much greater yield increases with applied nitrogen than were the tall varieties.

Early work by Smith (1934) in maize, showed that although many inbred lines behaved very much alike, a few showed distinct differences in dry weight when grown with a limited phosphorus supply. These same inbreds did not show a differential response to low nitrogen.

Mitchell *et al*. (1953) found a differential response among oat varieties to phosphorus. Mitchell (1957), working with barley, again found differential response among varieties.

Finn and Mack (1964) found differential response to phosphorus in orchardgrass. Crossley and Bradshaw (1968) found varietal differences in response to phosphorus in rye-grass and orchardgrass.

Differential response has also been found among legumes. Levesque and Ketcheson (1963), working with alfalfa, found that Dupuits yielded better than Ladak at low phosphorus levels.

Foy *et al*. (1967) observed differential tolerance to aluminum in *Phaseolus vulgaris* L. and *Phaseolus lunatus* L.

Varietal differences have been studied more intensively in soybeans than in other legumes. Howell (1954) showed differences between the varieties Lincoln and Chief. Later work by Howell and Bernard (1961) demonstrated that soybean varieties differed in tolerance to high levels of phosphorus. The more tolerant varieties also proved to be the most responsive. Dunphy *et al*. (1966) took a much more comprehensive approach to differential response in soybeans, observing great variability in many varieties.

Once established that nutritionally different types exist within a species the question arises as to how these differences came about. Snaydon and Bradshaw (1962), working with Trifolium repens L., noted that nutritional races can arise in nature as a result of mutations and natural selection. Available nutrient levels in the soil might be an important factor in natural selection of nutritional types. If a soil becomes depleted in a given element, those types which extracted and utilized that element more efficiently would probably set more viable seeds. Over time, the population would become adapted to its edaphic environment. Reitz and Meyers (1944), working with wheat, found that varieties adapted to similar soils responded in a similar manner to fertilizers. Conversely, varieties adapted to different soils demonstrated differential response.

It has been shown that varieties respond differentially; and that nutritionally distinct populations can arise through genotypic differences in ability to produce viable progeny. The genetic bases for nutritional differences have been shown by several authors including Pope and Munger (1953), Bernard and Howell (1964), Epstein and Jeffries (1964), and Crossley and Bradshaw (1968).

The genetic differences must produce physiological and/or morphological differences. The physiology of nutritional differences has been investigated by several workers.

Brown et al. (1961) and Brown and Weber (1967) considered differences among soybean genotypes and found that varieties differed in their capacity to reduce iron at the root surface. The varieties with the greatest reducing capacity showed greater uptake. Weiss (1943) studied internal pH differences of many genotypes. A low pH was conducive to iron solubility, hence availability in the plant. Ambler and Brown (1969) concerned with zinc deficiencies, noted that varieties with greater Fe and P uptake demonstrated severe zinc deficiencies.

Morphological differences involving root:top ratios have been considered in corn by Lyness (1936), in alfalfa by Levesque and Ketcheson (1963), and in soybeans by Fletcher and Kurtz (1964). DeTurk (1933), working with corn, found that larger root systems were capable of exploring a larger soil volume, facilitating greater nutrient uptake. Smith (1934) considered the ratio of secondary to primary roots in corn in relation to nutrient absorption.

The possibility of utilizing varietal differences dates back some years. Gregory and Crowther (1928) noted the possibility of selecting varieties adapted to nutrient deficient soils. Stringfield and Salter (1935) believed it was necessary to consider varietal curves for yield, with special reference to the yield of a standard variety, at different levels of soil fertility. They indicated that if certain varieties are particularly well suited to either the better or the poorer soils, they should be identified and recommended accordingly. Vose (1963) noted that the breeder of any field crop must take so many factors into account, that there is little inducement to consider an additional factor such as nutritional efficiency, unless forced to do so by extreme requirements. If advances in crop yields are to be maintained, then deliberate selection for nutritional efficiency seems desirable.

Some attention should be directed toward identifying and expressing varietal differences in response. The work by Holmes and MacLusky (1955) indicated the need to work with large numbers of varieties to have an idea of the variability within a species. Reitz and Myers (1944), and Finn and Mack (1964) pointed out that a constant problem in evaluating nutrient response is that varieties can respond differentially to climatic factors. Since many of these factors are difficult to control in the field, it is easy to mistake differential response to a climatic factor, for differential response to the elements under study. It is also important to consider whether the effects of the element are direct or indirect.

Response can be expressed in different manners. Dunphy et al. (1966) expressed yield response simply as the difference between the fertilized and non-fertilized treatments, while Schillinger (1970) expressed yield response as a percentage of the check.

MATERIALS AND METHODS

Greenhouse, field, and hydroponics experiments, although independent of one another, are related in that they provide information needed to obtain insight into the problem of differential response.

Greenhouse Experiment

Factorial Components and Experimental Design

A randomized complete block design was employed with factorial components of 124 varieties, two fertility levels, and three replications.

Location of the Experiment

The greenhouse experiment was conducted at the Inter-American Institute of Agricultural Sciences (IICA), Turrialba, Costa Rica.

Preparation of Soil

The potting soil was taken from the top-soil of a hillside in Pacuare, Costa Rica. In Pacuare, beans are grown under primitive agricultural conditions described later. The soil was fumigated with methylbromide to reduce the incidence of disease organisms, then approximately 6.5 kg of air dry soil was placed in each pot.

Soil Analysis

Nitrogen was determined using the Semimicro-Kjeldahl method described by Black (1965). The Bray 1 method (1945) was used for phosphorus determination. K, Ca, and Mg were determined by atomic absorption. Cation exchange capacity (CEC) was determined according to the method described by Bower (1952). The organic matter was determined using a method described by Saiz Del Rio and Bornemisza (1961). The pH was determined in a 1:1 soil-water mixture. The soil test results are tabulated under "Pacuare" in Table 9 of the Appendix.

Fertilizer

Two fertilizer treatments were used to create high and low fertility conditions. The low fertility treatment (T_0) was the control. The high fertility treatment (T_1) consisted of a 15 gram application of a 10-30-0 fertilizer to each pot. The fertilizer was formulated by mixing 22.2 grams of urea (45% N), 64.4 grams of triple-superphosphate (46% P_2O_5), and 13.5 grams of quartz sand to act as inert material. The fertilizer was deposited in a small area in the center of the pot about 6-8 cm below the soil surface.

Selection of Varieties

One-hundred and twenty-four varieties of *Phaseolus vulgaris* L. were selected from the germplasm collection at Turrialba. The varieties were selected to include representatives from distinct geographical and ecological regions. These 124 varieties probably are a representative sample of the population of varieties in *Phaseolus vulgaris* L. A list of these varieties is found in Table 8 in the Appendix.

Planting and Harvesting

Five seeds were planted in each pot, and after 7 days the plants were thinned to three per pot.

The mature plants were harvested and measurements were taken of yield and the yield components. Yield, pods/plant, seeds/pod, and weight/seed will be referred to as W, X, Y, and Z respectively.

Presentation of Data

Analyses of variance, as well as all other procedures to be described, were conducted for W, X, Y, and Z.

Histograms were used to show the range and distribution of data at high and low fertility levels and the distribution of response values.

Scattergraphs and line-graphs were used to indicate the feasibility of predicting response.

In considering the problem of expressing differential response, three methods were utilized. In method 1, each individual variety was compared to the population mean. The role of the population mean was similar to that of a standard variety, although the population mean contained many more observations than did the individual varieties. The differences $(\bar{d} - \bar{d})$ was calculated as shown for each variety and the population mean:

$$(\bar{X}_{pt_0} - \bar{X}_{vt_0}) - (\bar{X}_{pt_1} - \bar{X}_{vt_1}) = \bar{d} - \bar{d}$$

In method 2, response values were determined as shown in Figure 1. It might also be mentioned that the values obtained in this manner are equivalent to the $(\bar{d} - \bar{d})$ values obtained in method 1. In Figure 1 the mean value for the population of all varieties at T_0 and T_1 are represented by the dot-dash line. The difference between the T_1 and T_0 population values is considered to be the average effect of fertility on the population of varieties. The fertility effect is calculated as follows:

$$\bar{X}_{pt_1} - \bar{X}_{pt_0} = F \text{ (fertility effect)}$$

$$14.17 - 4.71 = 9.46$$

At low fertility, varieties will fall on, above, or below the population mean at T_0. Variety 15 will be used again for illustrative purposes. The T_0 value for variety 15 is 8.00 ($\bar{X}_{v15t_0} = 8.00$). This represents a deviation of 3.29 from the population mean at T_0, and is termed the "variety effect." The calculation is as follows:

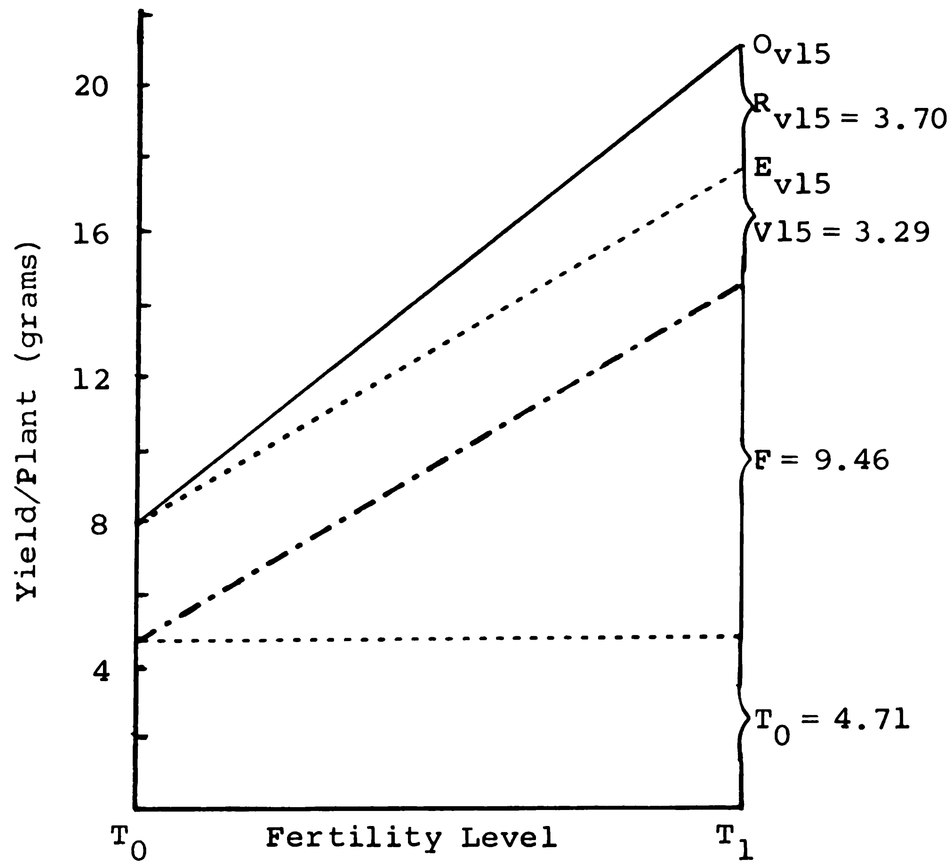

Figure 1. Model for deriving response values.

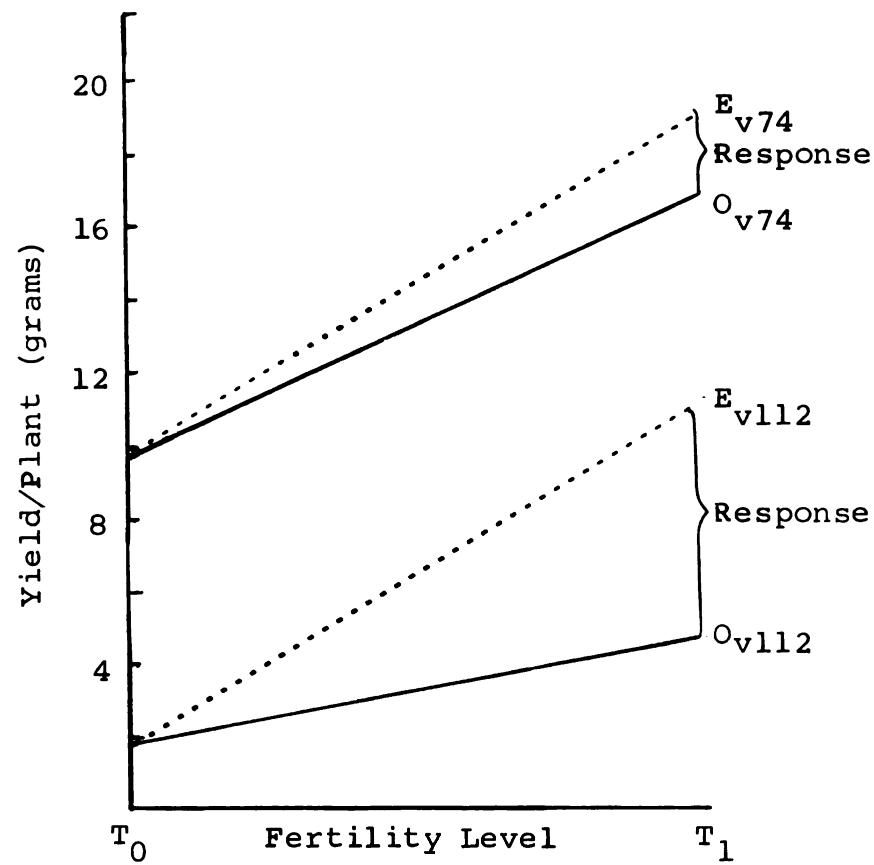

Figure 2. Comparison of the response values for varieties 74 and 112.

$$\bar{X}_{v15t_0} - \bar{X}_{pt_0} = V_{15} \text{ (variety effect)}$$

$$8.00 - 4.17 = 3.29$$

An expected point can be calculated for variety 15 at T_1 (E_{v15}). It is assumed that variety 15 will be affected by the T_1 treatment in a similar manner as the population of varieties was. Therefore the expected point for variety 15 at T_1 would be the following:

$$E_{v15} = \bar{X}_{pt_0} + V_{15} + F$$

$$= 4.71 + 3.29 + 9.46$$

$$= 17.46$$

The response value, expressed as the difference between the observed value (O_{v15}) i.e., $\bar{X}_{v15t_1}$ and the expected value (E_{v15}) is calculated as follows:

$$R_{v15} = O_{v15} - E_{v15}$$

$$= 21.16 - 17.46$$

$$= 3.70$$

The varietal response demonstrated here ($R_{v15} = 3.70$) is equal to the ($\bar{d} - \bar{d}$) value calculated for variety 15 using the first method.

In method 3, response was calculated as a percentage of the check as follows:

$$\frac{\bar{X}_{v15t_1} - \bar{X}_{v15t_0}}{\bar{X}_{v15t_0}} \times 100 = \% \text{ response}$$

This method is not definitive since the percentage expression can be easily misinterpreted. In Figure 2 the varieties 112 and 74 illustrate this point. By the percentage method variety 112 is shown to be a better responder than variety 74. The values are 157% and 80%, respectively, as shown in Table 8 in the Appendix. The small T_0 value for variety 112 permits this large percentage expression, whereas the larger T_0 value for variety 74 makes its percentage response small. This makes low T_0 producers appear as higher responders and high T_0 producers as lower responders. Using the first two methods, varieties 112 and 74 have values of -6.61 and -1.96, respectively. Although both values are negative, the important point is that by these methods variety 112 shows a lesser ability to respond than does variety 74; whereas by the percentage method variety 112 is superior in response to 74. In Figure 2, this point is supported by the fact that variety 74 more nearly approaches its expected value than does variety 112.

Path Coefficients were determined under both T_0 and T_1 conditions. The procedure is described by Duarte (1966).

Field Experiment

Location of the Experiment

The experiment was conducted at two locations in Costa Rica. The location at Alajuela (L_1) is in an intensive bean growing area, while the location at Turrialba (L_2) is not in a zone of commercial bean production.

Factorial Components and Experimental Design

The factorial components consisted of 16 varieties, 3 levels of N, 4 levels of P, 2 locations, and 3 replications. A split-plot design was employed. Fertility treatments represented the top-split, and varieties the sub-split.

Soil Analysis

The methods of soil analysis were the same as those used in the greenhouse experiment. The results are tabulated under "Alajuala" and "Turrialba" in Table 9 in the Appendix.

Varieties Used

The 16 varieties used in the experiment are listed in Table 10 in the Appendix. They are representative from various different geographical and ecological regions.

Fertilizer Treatments

The three nitrogen levels were 0, 100, and 200 kg per hectare. Phosphorus levels were 0, 200, 400, and 800 kg per hectare.

Planting and Harvesting

At planting the fertilizer was banded in a trench 6-8 cm deep. The fertilizer was covered with 2-4 cm of soil to prevent direct seed-fertilizer contact.

Each plot consisted of a row 1.5 meters long with seeds planted at 10 cm intervals. One meter row spacing was used.

Five mature plants from the center of each row were harvested. Data for yield and the yield components were obtained from these plants.

Statistical Analysis

Analyses of variance were conducted. The data were presented graphically and in tables to aid in the interpretation of results.

Interaction LSD's were calculated to determine over which nutrient levels varieties interacted differentially.

Hydroponics

Factorial Components and Experimental Design

The factorial components included 7 levels of P, 4 varieties, 3 plant parts, and 3 replications. A split-plot design with two sub-splits was used. P levels represented the top split, varieties the sub plots, and plant parts the sub-sub plots.

Varieties Used

The four varieties selected were Ahumado de Chirripo Linea 24 (variety 1), Jin-11-B (variety 2), P1-163-372 (variety 3), and 4-N (variety 4).

Nutrient Solution

A modified Hoagland solution "#1" and the "a" micronutrient supplement described by Hoagland and Arnon (1939) were used. KCl and H_2PO_4 replaced KH_2PO_4 as K and P sources.

To each liter of nutrient solution 0.55 cc of 1 molar NaCl, 1.0 cc of 0.5 molar $Na_2SiO_3 \cdot 9\ H_2O$, and 1.0 cc of a 0.5% Fe-EDTA were added.

The micronutrient supplement was applied every 10 days and the Fe-EDTA every 5 days.

To prevent micro-organism growth, Dicristicina (streptomycin-penicillin mixture) was applied at the rate of 1,000 units of penicillin per liter at the onset of the experiment.

Phosphorus Treatments

The phosphorus treatments were 2, 5, 8, 11, 14, 17, and 20 ppm. The P source was H_3PO_4.

Set-Up and Planting

The 16 liter nutrient solution containers were coated with an inert asphalt base paint, and wooden lids with five holes were placed over them.

Aeration was supplied constantly and the pH was maintained at approximately 6.0 using NaOH. The solution was changed every 15 days.

The seeds were germinated in vermiculite and one of each of the four varieties was transplanted 10 days after germination. The plants were held in place with sponge rubber wrapped about a portion of the stem.

Harvest and Preparation for Analysis

The varieties possessed different maturity dates and were harvested at the onset of flowering. It is believed that they were at a similar stage of physiological development.

The plants were divided into root, stem, and leaf portions to be analyzed separately. The material was oven dried at 105° C, weighed, and ground in a Wiley mill.

Mineral Analysis

The plant material was ashed for 12 hours at 550° C. The ash was dissolved in HCl and H_2O as described by Singh (1968). The extracts were analyzed for P, K, Ca, and Mg. P was determined according to a method described by Taussky and Shorr (1953). Potassium was determined flame-photometrically, and Ca and Mg by atomic absorption.

Analysis of Data

Analyses of variance were made for P, K, Ca, and Mg concentrations in the tissue. The data are presented graphically and in tables to aid interpretation. Duncan's Multiple Range Test for mean separation, and interaction LSD's were calculated where appropriate.

RESULTS AND DISCUSSION

Greenhouse Experiment

The analyses of variance for greenhouse results are shown in Table 1 for W, X, Y, and Z. The variety (V), fertility (F), and variety x fertility interaction effects (VxF) were all significant for yield and the yield components.

As Figures 3-5 demonstrate, W, X, and Y are approximately normally distributed at T_0, while the Z distribution appears skewed to the right (Figure 6). A logarithmic transformation of the data would make the Z distribution approach normality. The T_0 mean values are given in Table 11 in the Appendix for W, X, Y, and Z.

In Figures 7-10 the distributions for W, X, Y, and Z are shown at T_1. The T_1 mean values are given in Table 11 in the Appendix. The W distribution is different at T_0 than at T_1. This can be seen comparing Figures 3 and 7. At T_1 there has been an increase in frequency immediately above the mean ($\overline{X}$ to +0.5s), a decrease in the interval -0.5s to -1.5s, and an increase in the number of varieties having values below the -1.5s value. A plausible explanation is that the mean rises for all varieties, but does so disproportionately, more for some than for others. At the T_0

Table 1. Summary table of analyses of variance for the Greenhouse Experiment at Turrialba (1968)

Source	d.f.	Mean Squares			
		Yield/Plant (W)	Pods/Plant (X)	Seeds/Pod (Y)	Weight/Seed (Z)
Total	743				
Reps.	2	12.81 N.S.	3.07 N.S.	0.39 N.S.	0.0036 N.S.
Fert.	1	16,542.29**	7,064.95**	89.57**	0.1181**
Variety	123	38.92**	25.30**	3.45**	0.0535**
Var. x Fert.	123	14.77**	9.34**	0.48**	0.0030*
Error	494	9.29	5.05	0.35	0.0023

*Significant at .05 level; **Significant at .01 level.

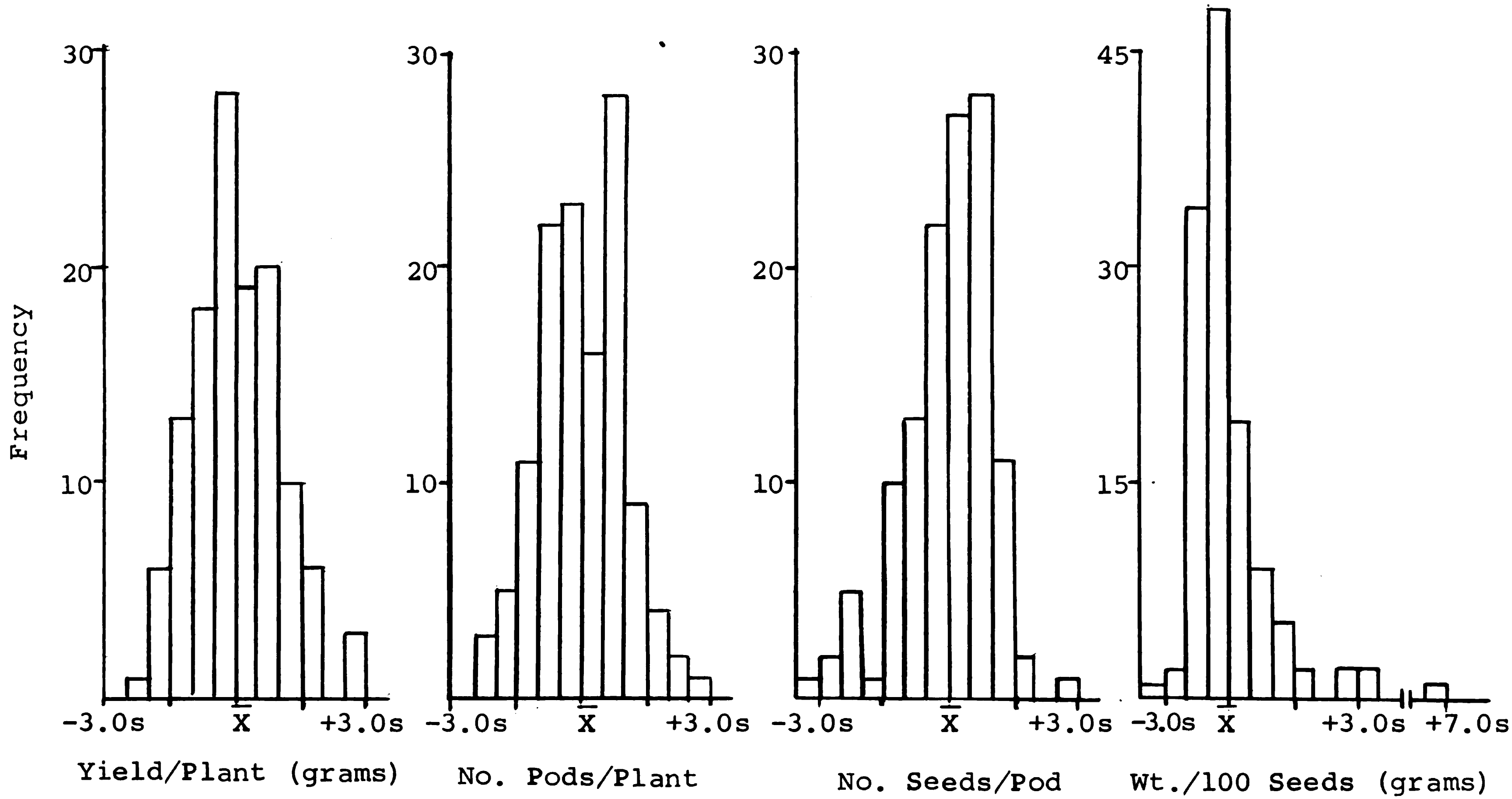

Figure 3 Figure 4 Figure 5 Figure 6

Figures 3-6. Histograms of yield and the yield components at low fertility level (T_0)

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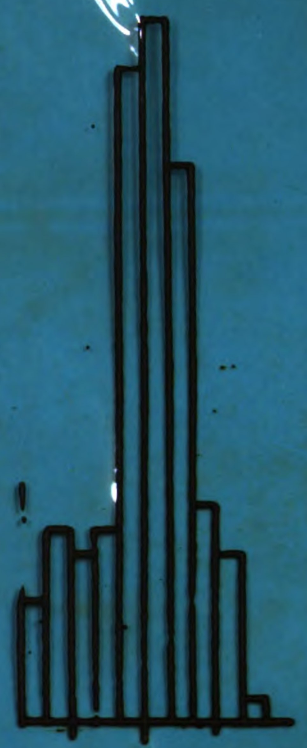


Figure 7

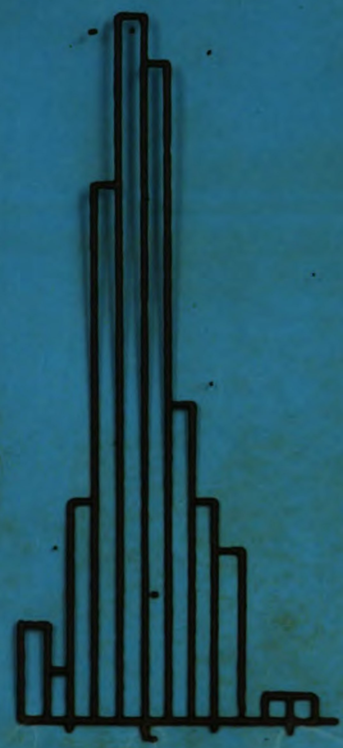


Figure 8

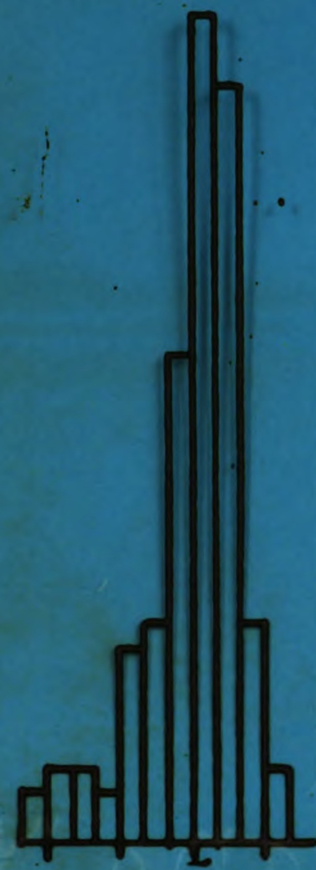


Figure 9

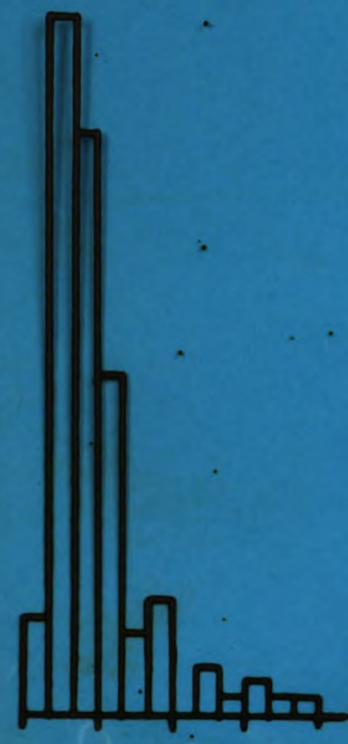


Figure 10

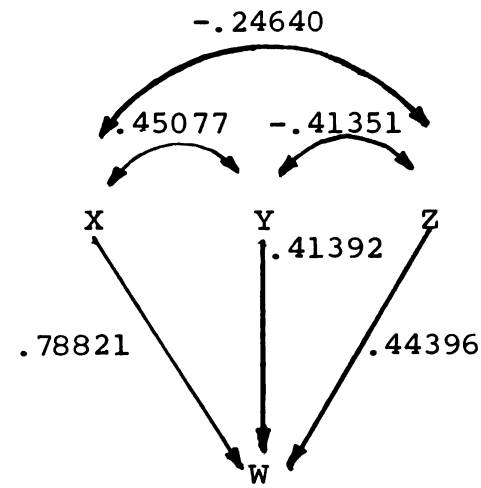
Figures 7-10. Histograms of yield and the yield of components at high fertility level (T_1)/

level, in the interval -0.5s to -1.5s, varieties may be found which demonstrate low yield potential, but are approaching this potential at the low fertility level. Varieties possessing a higher potential, but not nearly approaching their potential may also be found in this interval. At the high fertility level, the varieties possessing the greater potential increase more than do those possessing the lower potential, separating distinctly varieties which showed little difference at the T_0 level. The X distribution for T_0 (Figure 4) and T_1 (Figure 8) also show differences. At high fertility, higher frequencies are found in the -0.5s to +0.5s interval, and lower frequencies in the +0.5s to +1.0s interval. This represents a tendency to move from the +0.5s to +1.0s interval toward the mean. This change could indicate that some varieties are not increasing proportionately, causing a relatively lower ranking.

The Y distribution shows some skewing to the left at T_1 not present at T_0 (compare Figures 5 and 9). The skewing to the left for Y may be occurring because at high fertility, the upper limit of the biological potential of Y for this sample of varieties is being approached.

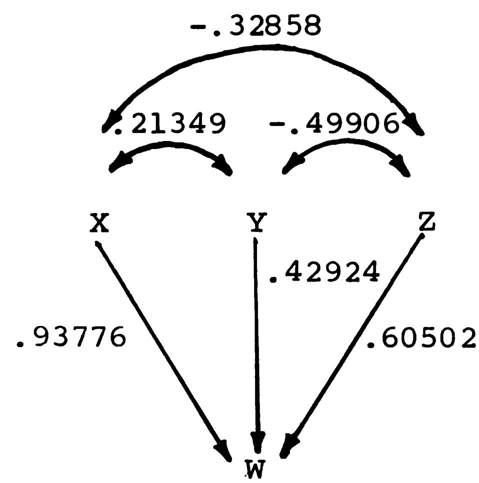
The Z distributions (Figures 6 and 10) show skewing to the right at both T_0 and T_1, but the effect is accentuated at T_1. The increased skewedness may also indicate that there are lower biological limits in seed size, below which survival is greatly impaired.

The fertility effect was significant for W, X, Y, and Z. Although all increases are significant at T_1, much larger increases occurred in W and X than in Y and Z (Table 11, Appendix). The effect of the increased level of fertility on X, Y, and Z with respect to their contributions to W was further investigated by calculating path-coefficients for X, Y, and Z at both T_0 and T_1. Logarithmic transformation of all the data was necessary, since the effects of X, Y, and Z on W are not additive. The results are shown in Figures 11-12. In comparing T_1 with T_0, it is clear that X exerts a predominant influence on W at both T_0 and T_1. The effect of T_1 is mainly to enhance the role of X and Z in influencing yield. T_1 affects the Y value or path, but not significantly. At T_0 the correlation r_{xy} is positive. As X increases due to T_1 the r_{xy} decreases, but remains positive. T_1 increases the path from Z to W, but some of this comes at the expense of the r_{xz} and r_{yz} values, which become even more negative than at T_0. As the fertility level is raised from T_0 to T_1 the negative correlations between X and Z, as well as between Y and Z, become more negative. The positive XY correlation at T_0 also becomes smaller at T_1. These trends make possible the increases occurring in the X, Y, and Z paths at T_1. The increasing negative correlations of XZ and YZ, as well as the decreased positive correlation of XY may indicate that a greater internal stress or competition is occurring at T_1 than at T_0 among the yield components. This competition could be for certain growth inputs



Low Fertility (T_0)

Figure 11



High Fertility (T_1)

Figure 12

Figures 11-12. Path coefficients at low (T_0) and high (T_1) fertility levels.

such as mineral nutrients, photosynthate, etc. At first, it might be expected that less competition would occur among the components at T_1, at least for the mineral elements, since additional nutrients were applied. However, since X, Y, and Z appear to develop in a sequential manner, the increment of fertilizer may increase X more than Y and Z. Once X has been increased at the T_1 level, sufficient growth inputs may not be available to increase Y and Z proportionately. The degree to which X could develop under T_0 conditions was so low that it offered little competition for resources needed by Y and Z. Although X offered little competition, the total amount of growth inputs available were so low that Y and Z showed lower values than at T_1. At T_1, conditions were such that X was able to develop extensively. It thus competed strongly with Y and Z for the available resources. Though competition was more severe, more resources remained for Y and Z than at T_0, permitting them to increase slightly. The competition at T_0 and T_1 are at different levels of environmental resources.

From the T_0 and T_1 distributions it is seen that much variability exists in yield at both low and high fertility. High yielders at T_0 probably have greater internal nutrient requirements than do low T_0 yielders. That is, they have larger quantities of inorganic nutrients incorporated into the yield product. A simple analogy might be that it takes more bricks to build a larger building. The higher yielders are thus able to make more efficient use of the substrate. This efficiency could be accomplished by more efficient absorption, translocation, and/or utilization of the nutrients. At T_0 varieties 31 and 82 illustrate differences in efficiency, having values of 1.33 and 9.93 grams, respectively. At T_1 varieties 15 and 67 had the values of 21.16 and 5.20 grams, respectively, demonstrating differences in efficiency at high fertility similar to those found at low fertility.

Efficiency must be considered in terms of relative yields at a given fertility level. At T_0 the higher yielder is making more efficient use of that substrate. As the fertility level changes, the relative ranking of varieties can greatly change. The significantly high varieties of T_0 are 9, 15, 29, 66, 74, 82, 94, and 100. At T_1 they are 4, 6, 15, 34, and 94. It is seen that some varieties do appear in both groups, but others do not. The fact that different varieties appear in the two groups indicates different efficiency rankings at the different fertility levels.

The W, X, Y, and Z distribution for response values are shown in Figures 13-16. A summary of the response values is given in Table 12 in the Appendix. The response distributions are quite normal, but there are much stronger tendencies for varieties to group about the Y and Z means than about the W and X means. This indicates that fewer varieties are demonstrating appreciable response. In general, for W, X, Y, and Z, there is a wide range of

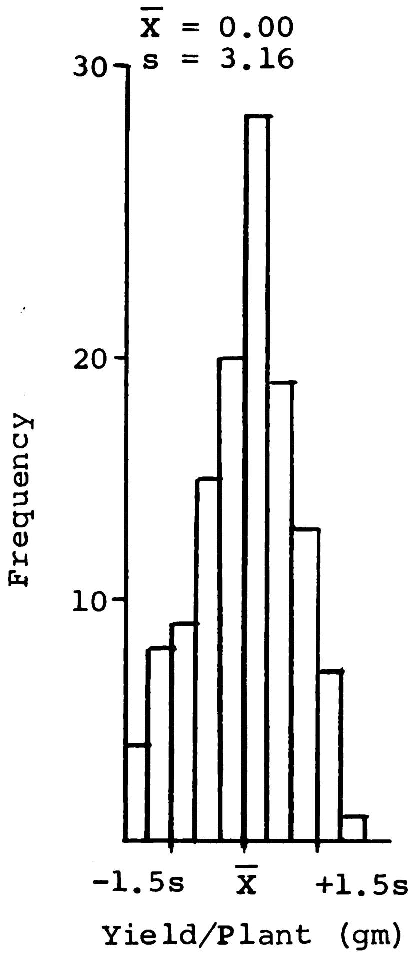


Figure 13

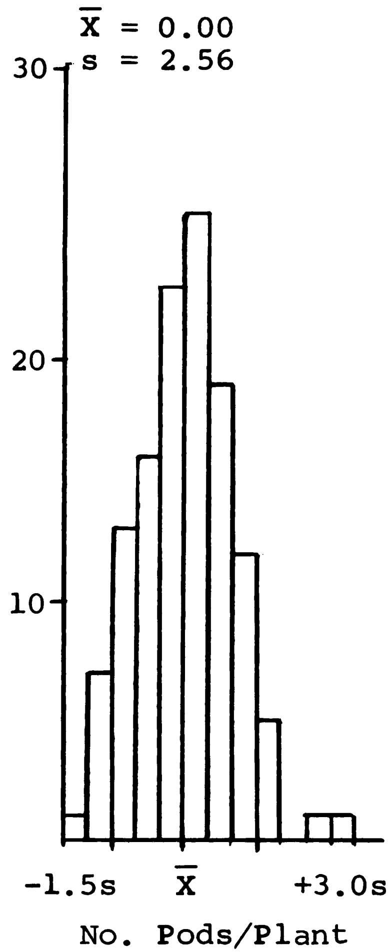


Figure 14

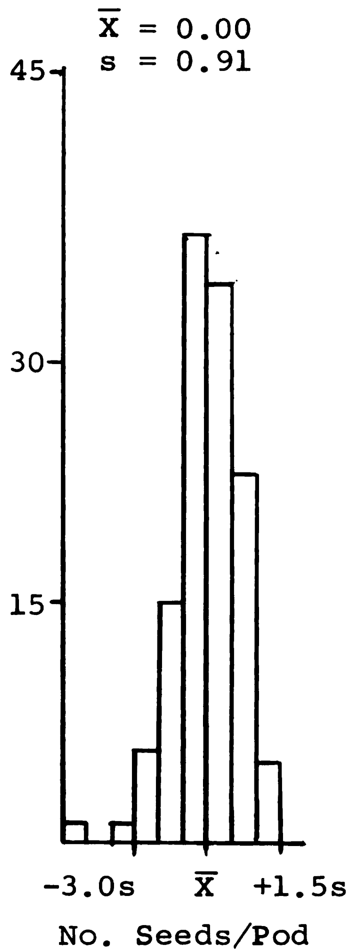


Figure 15

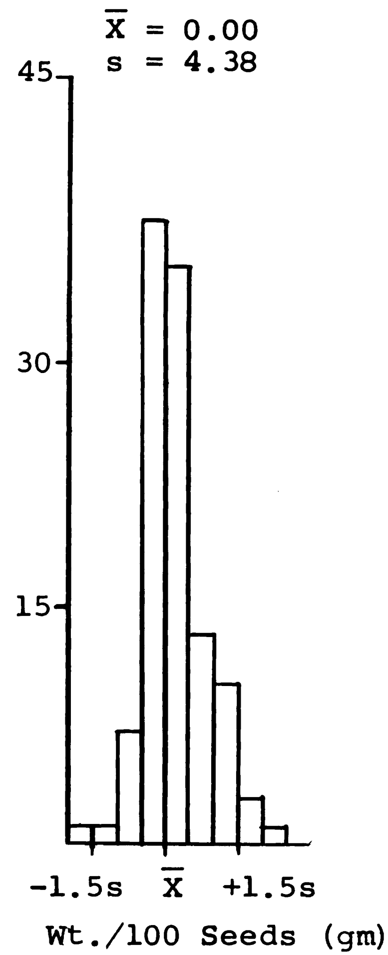


Figure 16

Figures 13-16. Histograms of response values for yield and the yield components.

response being demonstrated by the population of varieties in this experiment.

The inability to predict response to a given fertility increment from knowledge of its performance prior to the increment is shown in Figures 17-20. In these figures response values and deviations from the T_0 means are plotted. No trends or patterns develop, indicating that the direction and magnitude of response demonstrated by the varieties are not related to the T_0 values. Response therefore can not be predicted from knowledge of the T_0 values.

Response is probably determined by two factors. The first would be the nutritional level a variety requires in the medium to approach its optimal yield level; the second, the actual level available in the medium. The difference between these two should represent the response capacity of a variety.

Figures 21-24 show response values plotted against deviations from the T_1 mean. In Figures 21 and 22 a high correlation exists for W and for X (r values are .86 and .88 for W and X, respectively). This indicates that the response already realized can be predicted reasonably well from the T_1 values. The higher T_1 yielders generally demonstrated greater response, and the lower T_1 yielders less response. This was also true for X, but not for Y and Z. The higher T_1 yielders must have higher requirements for nutrients which were not being met at T_0, permitting a corresponding large response to the increment. Conversely, the lower yielders

Yield/Plant (grams)

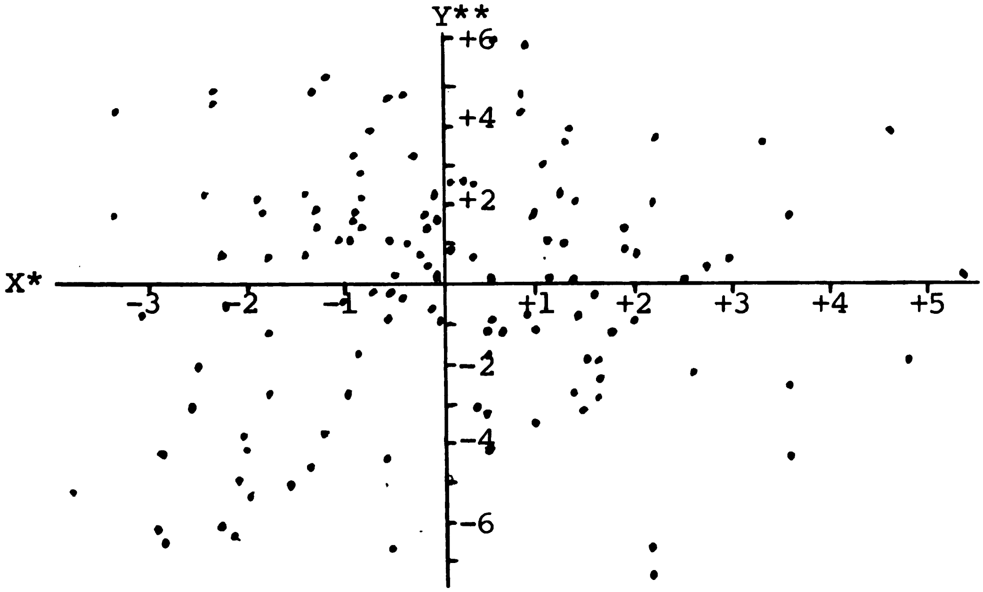


Figure 17

Number Pods/Plant

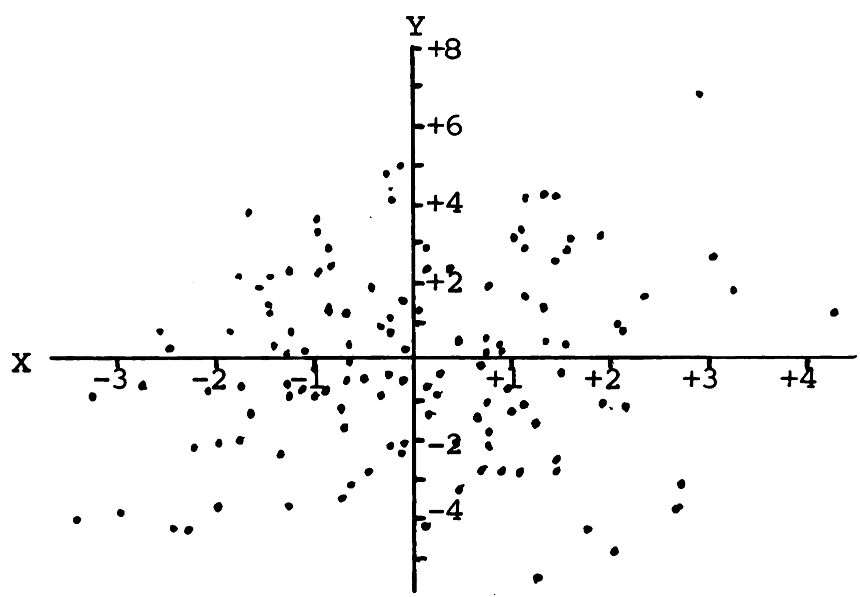


Figure 18

X* - Deviations from T_0 mean.

Y** - Response values.

Figures 17-20. Scattergraphs of response values and deviations from T_0 mean for yield and the yield components.

Number Seeds/Pod

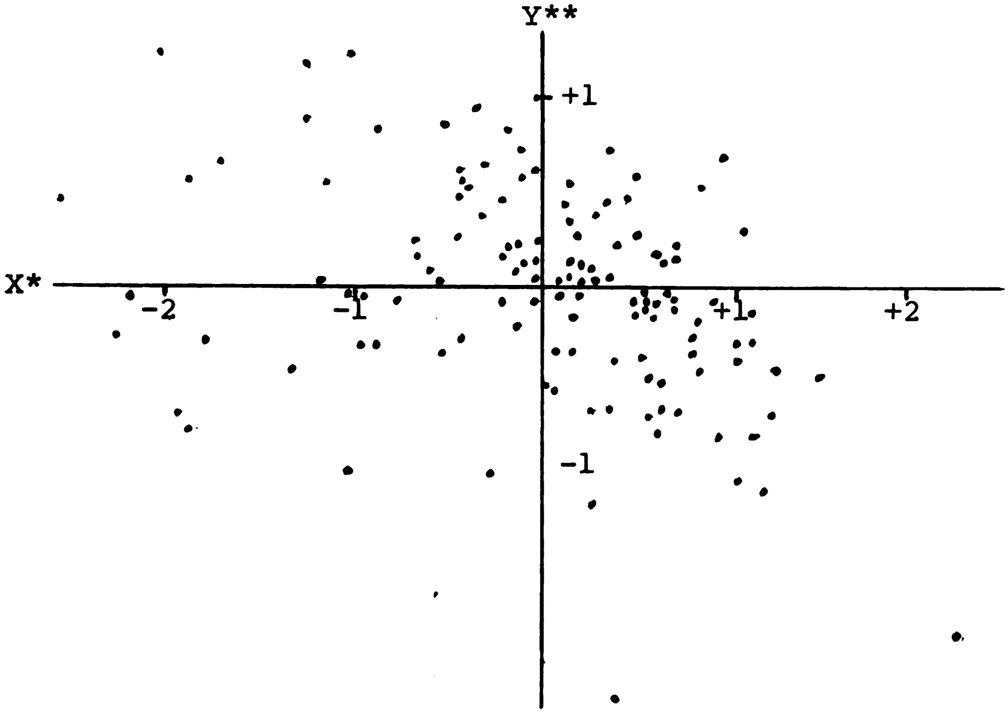
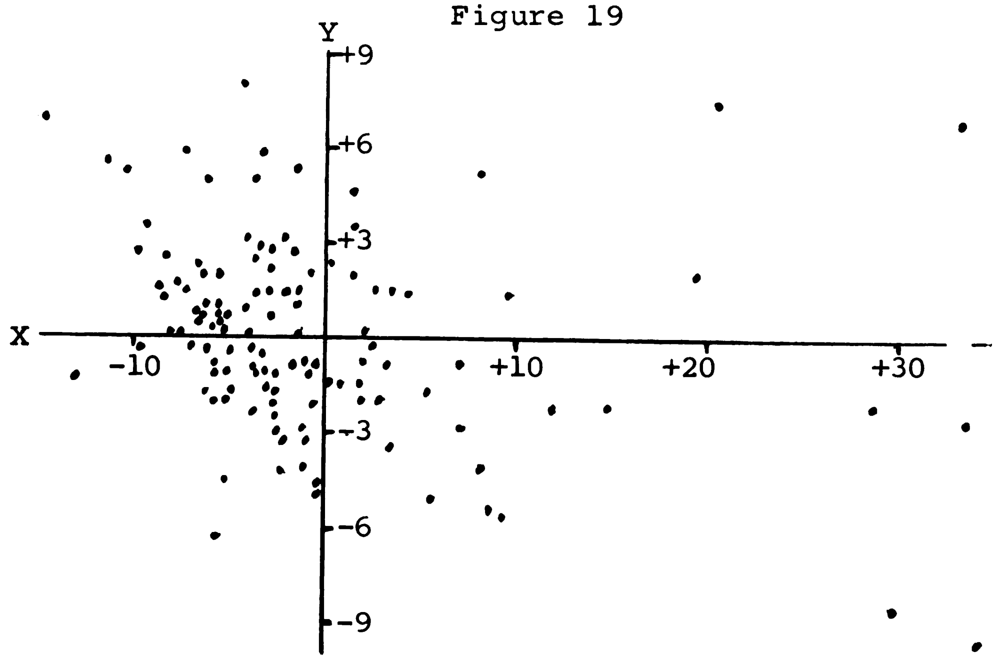


Figure 19



Weight/100 Seeds (grams)

Figure 20

Yield/Plant (grams)

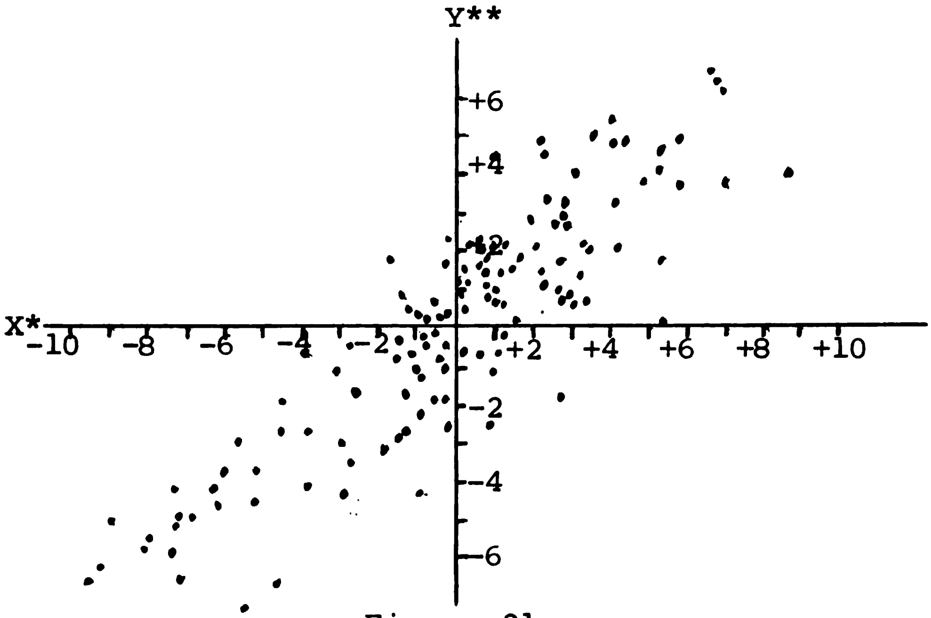


Figure 21

Number Pods/Plant

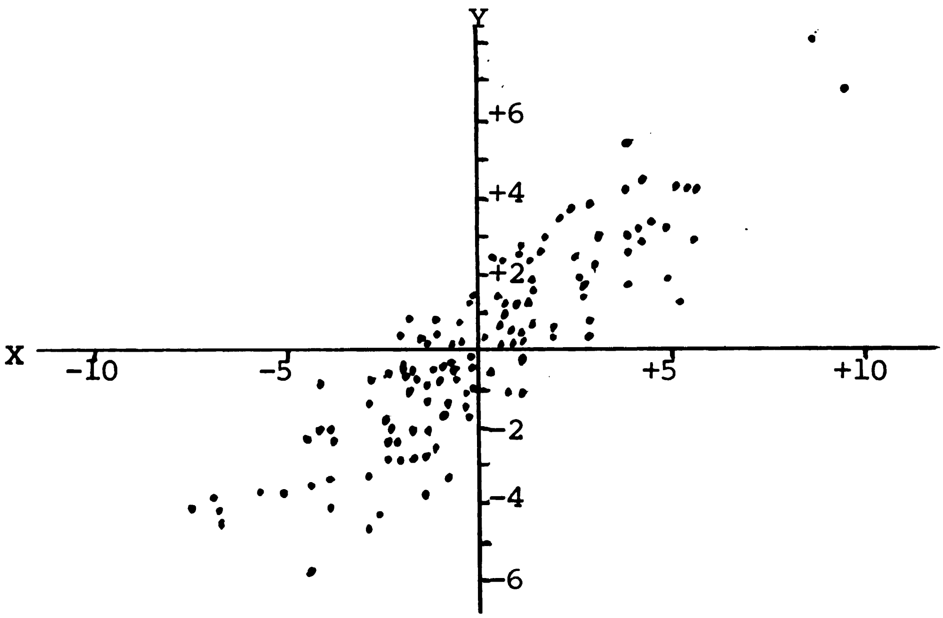


Figure 22

X* - Deviations from T_1 mean.

Y** - Response values.

Figures 21-24. Scattergraphs of response values and deviations from T_1 mean for yield and the yield components.

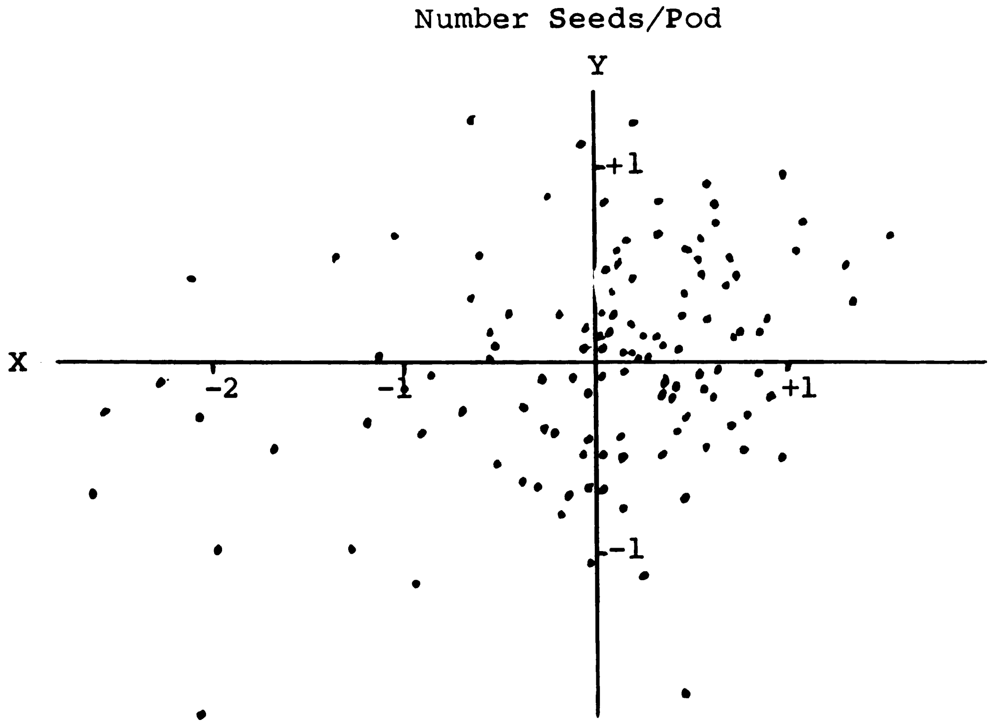


Figure 23

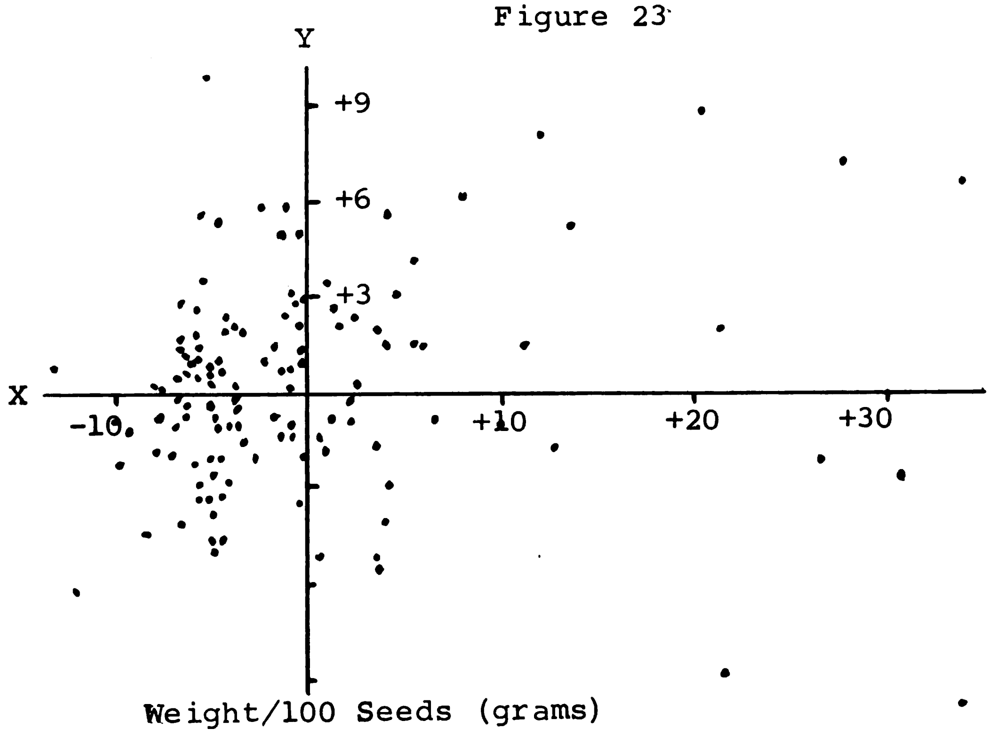


Figure 24

at T_1 must have had lower nutrient requirements which were being more nearly met at the T_0 level, thus producing lesser responses, or by our criteria, negative responses.

Table 2 lists the varieties demonstrating significant response for W. All the positive W responders showed positive response values for X, and all the negative responders showed negative values for X. Y and Z also are both quite variable for these varieties and followed no specific pattern. The significant W responses were therefore achieved differently by different varieties. In all cases, however, the X component appeared to be most predominant in determining the W response. Although most significant positive responders are found for Y and Z, their

Table 2. Varieties showing a marked response in "W"

		Components		
Variety	W	X	Y	Z
4	+6.02*	+4.16*	-0.07	+1.47
6	+6.28*	+3.05	+0.20	+2.77
30	+5.33*	+2.72	+0.03	-1.96
34	+6.50*	+2.27	+0.15	-0.24
22	-6.54*	-3.51	-0.11	-1.87
28	-5.04*	-2.39	+0.31	-3.91
32	-5.13*	-4.28*	+0.38	+7.91*
67	-5.15*	-4.06*	+0.53	+8.67*
73	-5.32*	-4.06*	+1.18*	-0.09
86	-7.40*	-5.62*	+0.21	-2.86
89	-5.95*	-4.39*	-0.09	-2.64
90	-6.28*	-3.84	-0.26	-2.13
103	-5.59*	-3.72	+0.01	+9.93*
107	-6.72*	-4.84*	+0.09	-3.48
112	-6.61*	-2.06	-0.97*	-1.22
64	+4.91*	+0.94	+0.92*	-5.04
106	+4.90*	+4.06*	+0.25	+2.15

effects are not enough to overcome the predominant influence of X. Also, a significant X value is not necessarily required to produce a significant W response, but intermediate X responders coupled with favorable Y and Z responses can produce a significant W response.

Table 3 shows the varieties demonstrating significant responses for X. In all cases, except variety 1, the signs of X and W values are the same. W, however, often is not significant even though X is. The effect of the significant responses in X are modified by opposite effects for Y and Z as illustrated by variety 73.

Table 3. Varieties showing a marked response in "X"

		Components		
Variety	W	X	Y	Z
1	-1.79	+8.05*	-2.44*	-0.31
4	+6.02*	+4.16*	-0.07	+1.47
8	+1.43	+4.39*	-0.78	+0.03
18	+4.71	+3.83*	+0.57	-0.73
29	-2.60	-4.39*	-0.01	+4.16
32	-5.13*	-4.28*	+0.38	+7.91*
37	+1.47	+3.60*	+0.49	-4.08
67	-5.15*	-4.06*	+0.53	+8.67*
73	-5.32*	-4.06*	+1.18*	-0.09
80	+2.24	+4.05*	-0.35	-1.41
81	-2.81	-3.95*	+1.22*	+2.75
86	-7.40*	-5.62*	+0.21	-2.86
89	-5.95*	-4.39*	-0.09	-2.64
90	-6.28*	-3.84*	-0.26	-2.13
96	+1.43	+6.61*	-0.78	+0.80
98	+3.94	+4.05*	+0.52	+1.36
103	-5.59*	-3.72*	+0.01	+9.93
106	+4.90	+4.06*	+0.25	+2.15
107	-6.72*	-4.84*	+0.09	-3.48

Table 4 lists the varieties demonstrating significant response for Y. For variety 1, the negative response in Y offsets the positive response in X, producing a negative W response. Variety 70 shows Y and Z offsetting the effect of X. The W values of the varieties in Table 4 are very strongly affected by Y, and in many cases overcomes or modifies the effect of X on W.

Table 4. Varieties showing a marked response in "Y"

		Components		
Variety	W	X	Y	Z
1	-1.79	+8.05*	-2.44*	-0.31
46	+1.33	+2.38	-1.16*	+0.26
55	+1.65	+1.27	+0.99*	+1.76
57	+0.80	+0.72	+0.87*	-1.38
62	-4.37	-2.94	-1.81*	+0.68
64	+4.91*	+0.94	+0.92*	-5.04
70	+4.76	-1.17	+1.24*	+5.12
73	-5.32*	-4.06*	+1.18*	-0.09
79	-0.27	-0.50	-1.03*	+1.56
81	-2.81	-3.95*	+1.22*	+2.75
85	-3.13	-0.73	-1.10*	-4.57
112	-6.61*	-2.06	-0.97*	-1.22
120	-1.25	-0.72	-0.94*	-2.23

In Table 5, the varieties demonstrating significant Z responses are shown. Except for variety 113, the significant Z values do not greatly affect the outcome of W. For variety 82, the positive W response value is due to error in equating the actual W values determined by direct weighing, to the W values obtained as products of X · Y · Z.

Table 5. Varieties showing a marked response in "Z"

Variety	W	X	Y	Z
		Components		
32	-5.13*	-4.28*	+0.38	+07.91*
67	-5.15*	-4.06*	+0.53	+08.67*
82	+0.11	-2.17	-0.07	-08.62*
103	-5.59*	-3.72*	+0.01	+09.93*
113	-3.62	-0.62	-0.67	-34.44*

An effort to determine whether the degree of improvement was in some way related to the response potential was studied only in a cursory manner. The level of improvement for the varieties can be seen in Table 8 in the Appendix. "Improved," means the variety has been included in a plant breeding program, while "unimproved" ones have not. The status of many varieties is not known, precluding any definite conclusions. Nevertheless, from the limited information there appears to be no specific pattern of response for either the improved or the unimproved varieties. The belief prior to this experiment was that the improved lines may show a greater response to applied nutrients than do the unimproved. The rationale was that the improved varieties have been grown under conditions of high soil fertility, and those types capable of utilizing a large quantity of nutrients may be more vigorous yielders. These plants would then be preferentially selected by the breeder because of their high yielding capacity. In other words, indirect selection for high response might occur through direct selection for high yield. It can be recalled that our data showed high correlation between T_1 yield and response.

The unimproved would not have been grown under conditions of high soil fertility under primitive agricultural conditions. The history of the soils would probably be one of steadily declining fertility. This decline would result from years of intensive cropping without the application of nutrients. Those types responding to, or using large quantities of nutrients would have no selective advantage. If those types capable of high response also have high requirements, they would be lost from the population under conditions of low fertility. In time a loss of the high responding types could occur. The information so far indicates that positive or negative response isn't specific to either the improved or the unimproved for either W, X, Y, or Z. These results are not unexpected if several points are considered. First of all, a high responder does not necessarily have a selective disadvantage under low fertility conditions. The high responder may be relatively well adapted to low fertility conditions as well as to high. Varieties 15 and 94 illustrate this point. The low fertility environment would simply not permit the high response character to be expressed. The type could thus be maintained in the population under low fertility conditions.

Another point is that primitive varieties are not necessarily grown under low fertility conditions, nor can it be assumed that soil fertility has declined in all bean growing areas over time.

The author witnessed distinct differences in bean cultivating practices in Costa Rica and earlier in Guatemala. In Pacuare, Costa Rica, some of the farmers practice a "slash and plant" type of agriculture. Most of the areas where these methods are employed are on mountain slopes covered with wild vegetation. The farmer prior to planting simply cuts down a portion of the vegetation leaving a dense mat of organic matter. He then broadcasts the bean seed on top of the decaying vegetation. The ground cover as well as the natural regrowth of vegetation prevents soil erosion. It also provides a nutrient source for the beans. The beans sown were of a viny indeterminant growth habit, capable of competing successfully with the other forms of native vegetation. This cropping system is extensive, and a single site is cropped only once every 3 years. Soil was analyzed from some Pacuare bean plots. The nutrient status, as shown in Table 9 in the Appendix under "Pacuare Beans," was very high. In Alajuela, Costa Rica, an intensive bean growing area where cultivation is clean (row-cropping), the soil fertility level is relatively low. Based on the above discussion it is seen that unimproved varieties are not necessarily grown under conditions of declining soil fertility. A more realistic approach might be that soil fertility with relation to time has done one of three things. Soil fertility could either remain constant, increase, or decrease. If this is true, and varieties are in equilibrium with their edaphic environment, then it follows that the unimproved group will be highly variable. This variability would then elicit great response variability to a given level of applied nutrients, if the medium prior to application is a constant for all varieties. Indeed, high, intermediate, and low response was observed in the unimproved group.

It may also be erroneous to expect modern varieties to demonstrate uniformly high response. Man often sacrifices high total yield in an effort to improve yield quality, or to have other desirable agronomic characters such as disease resistance.

Field Experiment

The analysis of variance for the field experiment is shown in Table 6. Location (L), nitrogen x location (NxL), location x nitrogen x phosphorus (LxNxP), variety x location (VxL), location x nitrogen x variety (LxNxV), and location x variety x phosphorus (LxVxP) are only of limited interest to this study. Some discussion of the simple location effect will be made, and the other effects of limited interest can be thought of as a result of interactions with it.

The location effect was significant for W, Y, and Z, but not for X. Figures 25-28 illustrate this. Since yield is a product of the yield components, the higher yield at

Table 6. Summary table for the analyses of variance for the Field Experiment at two locations in Costa Rica (1968)

Source	d.f.	Mean Squares			
		Yield/Plant (W)	Pods/Plant (X)	Seeds/Pod (Y)	Weight/Seed (Z)
Loc. (L)	1	15,141.00**	340.57 N.S.	80.569**	11,852.0**
L x Reps. (R)	4	832.17	321.02	1.090	28.0
Nit. (N)	2	5,658.35**	4,447.93**	2.141**	0.5 N.S.
Lin. N	1	9,628.59**	7,708.75**	0.041 N.S.	...
Quad. N	1	1,688.10**	1,187.16**	4.240**	...
N x L	2	1,311.37**	227.20 N.S.	0.335 N.S.	20.9 N.S.
Phos. (P)	3	381.37*	470.48**	0.054 N.S.	39.2 N.S.
Lin. P	1	292.79 N.S.	912.75**	...	...
Quad. P	1	522.57*	495.86*	...	...
Cub. P	1	41.08 N.S.	1.50 N.S.	...	...
P x L	3	288.73 N.S.	94.22 N.S.	0.165 N.S.	11.0 N.S.
P x N	6	267.35 N.S.	141.00 N.S.	0.294 N.S.	8.2 N.S.
P x N x L	6	338.44*	252.15*	0.352 N.S.	8.8 N.S.
Error b	44	121.92	91.03	0.358	17.7
Var. (V)	15	407.07**	1,056.82**	17.377**	1,384.9**
V x L	15	240.91**	125.83**	1.110**	80.5**
V x N	30	53.39 N.S.	36.68 N.S.	0.241 N.S.	5.9**
V x N x L	30	59.23 N.S.	42.82 N.S.	0.382**	5.1*
V x P	45	89.11**	69.82**	0.281 N.S.	3.7 N.S.
V x P x L	45	62.58 N.S.	37.68 N.S.	0.221 N.S.	5.2**
V x P x N	90	54.21 N.S.	43.15 N.S.	0.179 N.S.	3.8 N.S.
Error c	10	53.08	38.33	0.224	3.5

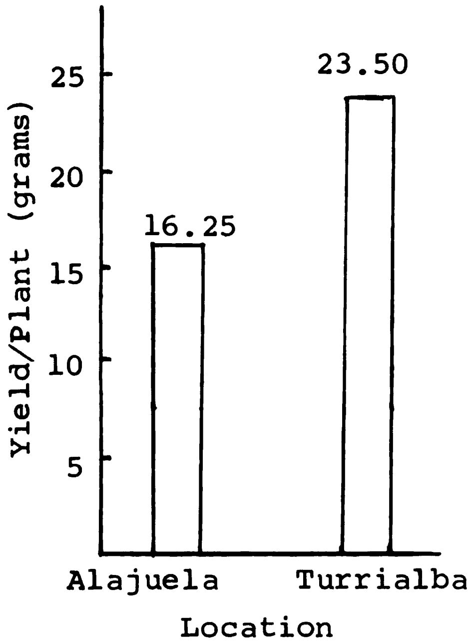


Figure 25

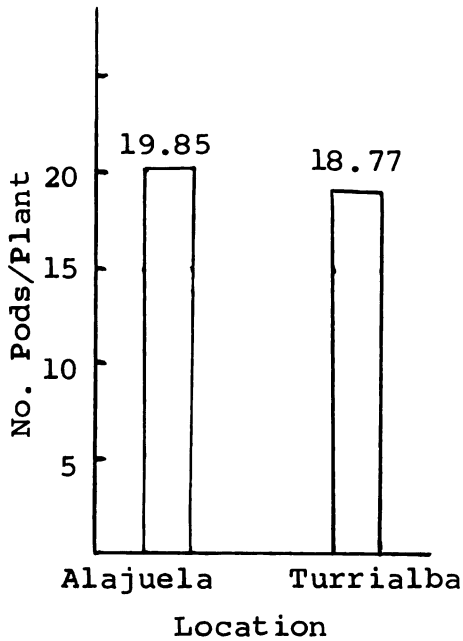


Figure 26

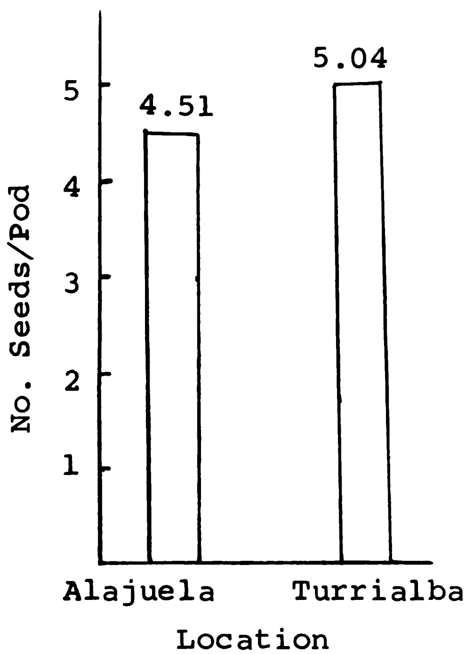


Figure 27

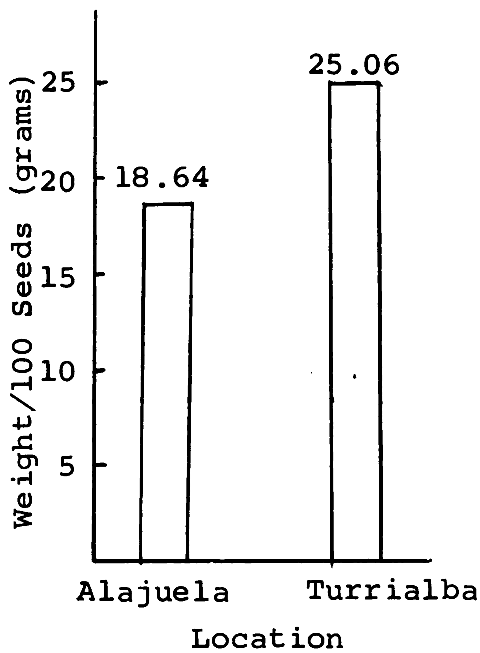


Figure 28

Figures 25-28. Location effects on yield and the yield components.

Turrialba (L_2) results from higher Y and Z values exhibited there. Since no difference exists for X, it is reasonable to assume that environmental factors at Alajuela (L_1), which may have limited yield, did not limit X, but did significantly inhibit Y and Z. These unfavorable environmental factors may not have been present during the period of pod set, or at least they may not have been as severe during that period. The unfavorable factors could have occurred later in the growing season, affecting the number of seeds which developed in each pod, and the degree to which they could develop. Another explanation might be that the limiting factors were present in environmental mileu throughout the entire period of plant development, and the differential tolerances of the components to those limiting factors were being exhibited. The tolerant component would be X, the less tolerant ones, Y and Z. Excessive rainfall, especially during the latter part of the life cycle occurred at Alajuela. The excessive rainfall combined with the heavy (high clay content), poorly drained soils, could have maintained excessive moisture and reduced the oxygen supply in the soil.

The NxL interaction was significant only for W. For both N increments, greater increases were realized at Turrialba.

The LxNxP interaction was significant for W and X. This indicates that the LxN interaction varies with the levels of P.

The VxL interaction is significant for W, X, Y, and Z. Differences in maturity dates could be a factor causing the varieties to show differences between locations, especially if some stages of development are more susceptible to adverse environmental factors than others. Differential tolerance to adverse environmental factors may also be present among the varieties.

The LxNxV interaction was significant for Y and Z only. For those components the LxV interaction differs with each level of N.

The VxPxL interaction was significant for Z only. This implies that the LxV interaction differs with each level of P.

The effects of major interest in this study are those of nitrogen (N), phosphorus (P), varieties (V), variety x nitrogen (VxN), and variety x phosphorus (VxP).

The nitrogen effect was significant for W, X, and Y, but not for Z (see Table 13, Appendix). When significant data were found, the trend relationships were calculated. For both W and X the linear and quadratic components were highly significant, indicating there was a tendency for W and X to increase with each nitrogen increment, but the increases were much greater for the first increment than for the second. For Y only the quadratic effect was significant. For X the first increment was the most critical and provided sufficient N for optimum growth, i.e., almost removes N as a limiting factor. Little response would be expected with the second increment.

For Y the first increment is beneficial, the second detrimental. The optimum level of N for Y has already been passed at the 200 kg level. Since no significant differences were found for Z, apparently the N level did not limit Z at the zero N level. It can be seen here that different optimum N levels exist for the different components. The increase in W with the first increment is contributed to largely by X and Y. The increase in W with the second increment appears to be largely due to the increase in X, since Y decreases and Z remains constant.

Of the two elements included in this experiment, the N effect was much greater than the P effect. This may be somewhat surprising since Phaseolus vulgaris is a legume, and the soils are low in P.

Although the bean is a legume, it has a very short life-cycle (10-16 weeks), and time may be required to establish the symbiotic relationship. In the early stages of growth sufficient N may not be available from N fixation to promote optimum growth.

The P effect is significant for W and X, but not for Y and Z (see Table 13, Appendix). Apparently the 200 kg/ha increment was sufficient to provide adequate P to approach optimum W and X values. Y and Z were not significantly affected by increasing P, indicating that P was not limiting Y and Z at the zero P level. The trend relationships for W show a significant quadratic component. There is a leveling off and no change after the first P increment. Both the linear and quadratic effect were highly significant for X. This means there was a tendency for X to increase with each P increment, but the lesser magnitude of increase due to the second increment, and the leveling off with the third, tended to produce a significant quadratic effect.

Varietal differences for W, X, Y, and Z were all significant. Bar graphs show varietal differences (Figures 29-32). Varieties can produce similar yield in different ways, using different X, Y, and Z values. Varieties 10 and 11 illustrate this point.

The VxN interaction was significant for Z only. Interactions occurred over both the 0-100 kg/ha and the 100-200 kg/ha intervals.

The lack of differential response to N in the other components indicate that these varieties responded similarly to N.

The VxP interaction was significant for W and X. To illustrate the significant VxP interactions, observe the yield changes which occurred with each P increment. For illustrative purposes two low and two high yielding varieties have been selected and plotted. Figures 33 and 34 represent the 0-200 kg/ha interval; Figures 35-36, 200-400 kg/ha; and Figures 37-38, 400-800 kg/ha. The two varieties plotted in each figure were shown by Duncan's Multiple Range Test to be not significantly different. The object of

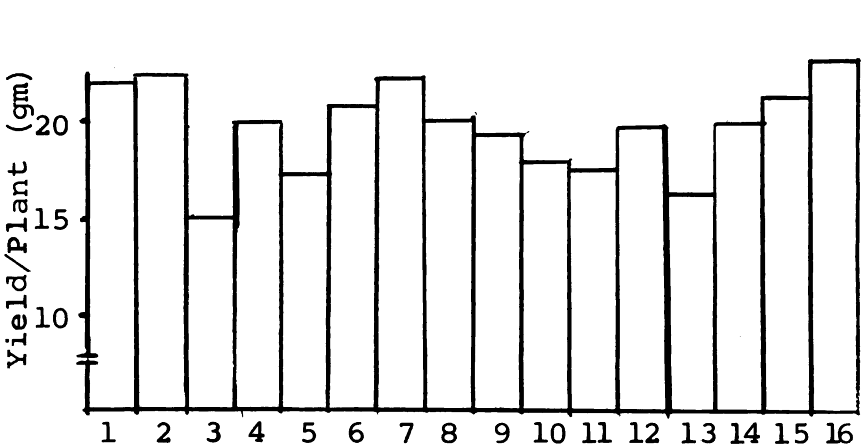


Figure 29

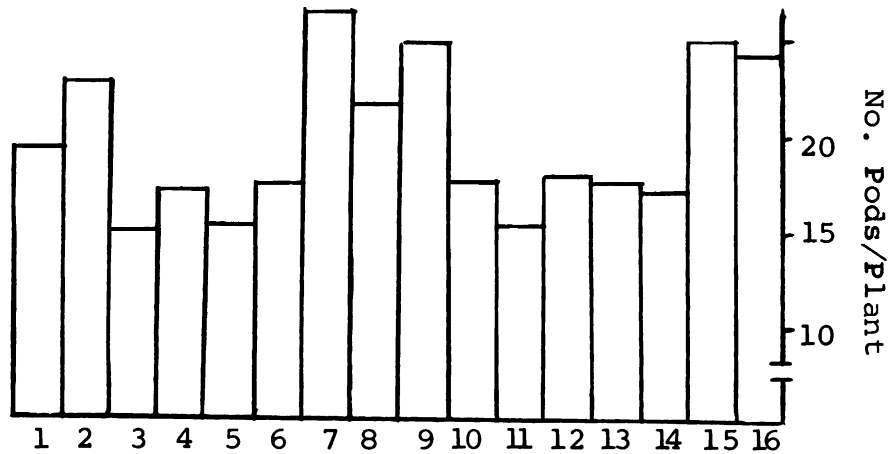


Figure 30

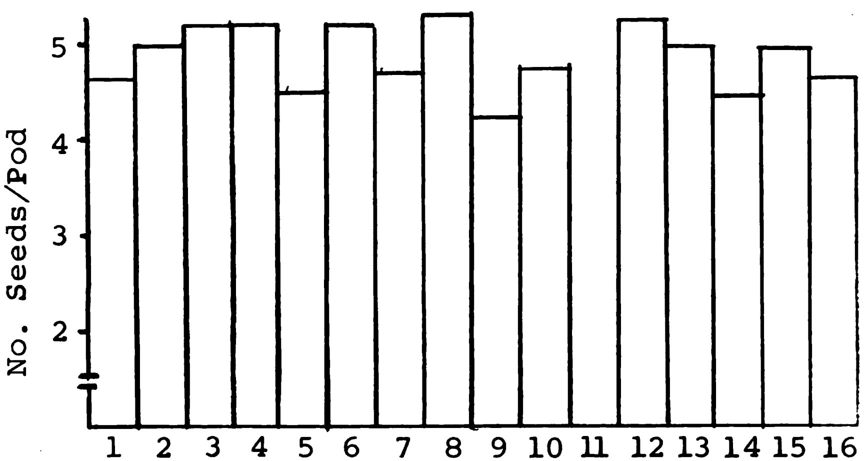


Figure 31

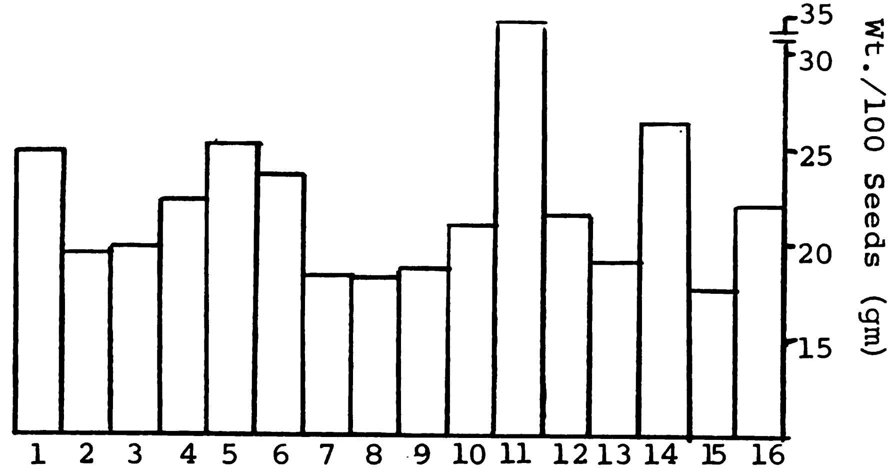
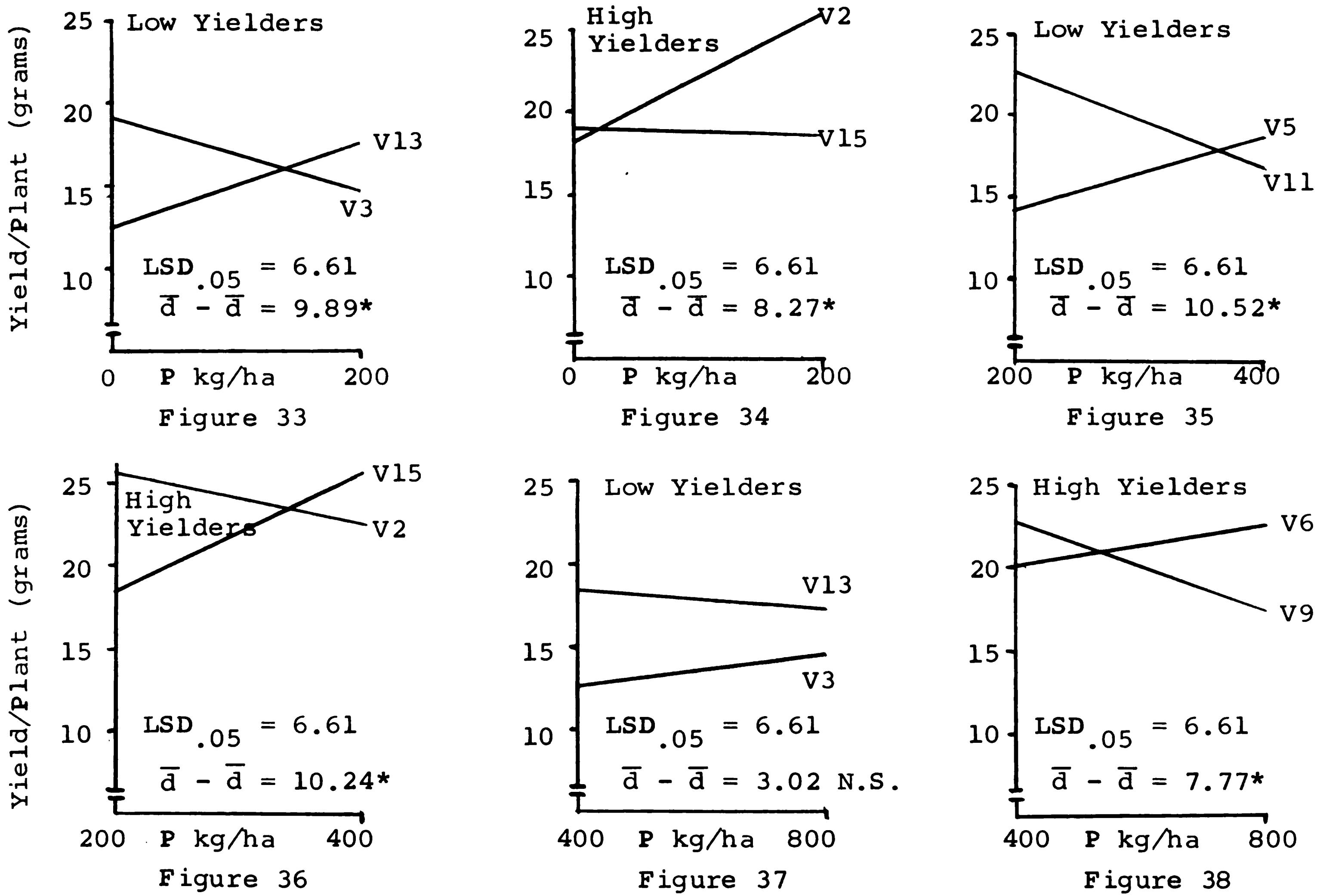


Figure 32

Figures 29-32. Varietal differences for yield and the yield components.



Figures 33-38. Varieties demonstrating variety x phosphorus interactions.

choosing two varieties for comparison, which are of seemingly similar yield characteristics, is to demonstrate that it is difficult to predict the direction or magnitude of yield change as we move from one given P level to another. Figures 33-38 show the significant VxP interactions over all intervals used in this experiment.

In Figures 39-45 an attempt is made to group the varieties according to the shape of curve demonstrated across the P levels. The first group (Figure 39) shows an increase with the first P increment. With further P increases there is little change. These varieties may not have been at their optimum P levels at zero P. The first increment supplied sufficient P, permitting these varieties to more nearly approach their yield potential. Subsequent P increments had little effect on their yield. Such a response could result from the following: (1) These varieties may be tolerant to P levels which exceed their required optima. (2) On the other hand, it may not demonstrate tolerance. (3) They may not be able to demonstrate a yield increase to additional increments of P because some other factor becomes limiting as additional P is added.

The second group (Figure 40) also demonstrates a great yield increase with the first increment, but with the second increment all varieties show a yield decrease. The first increment may again permit these varieties to more nearly approach their optimum yield. The yield decrease may result from an application of P above their optimum.

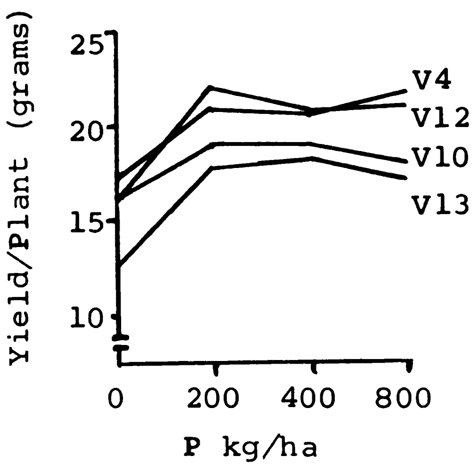


Figure 39

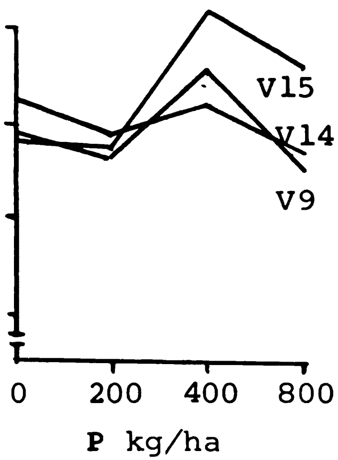


Figure 40

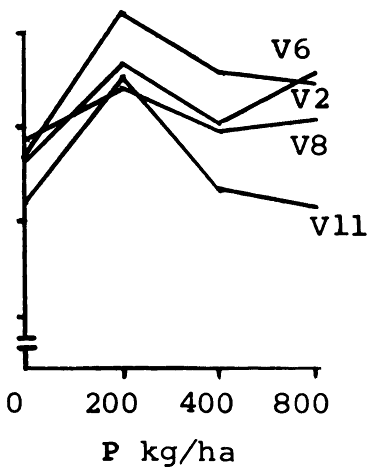


Figure 41

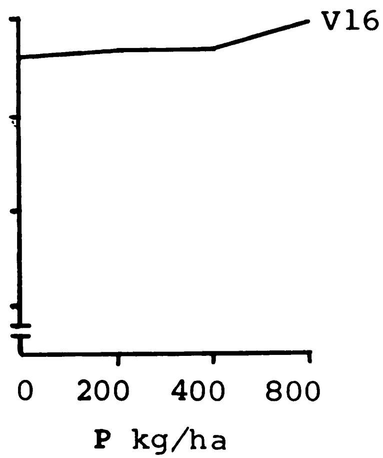


Figure 42

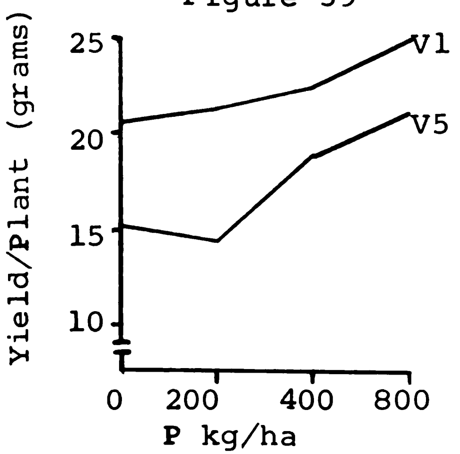


Figure 43

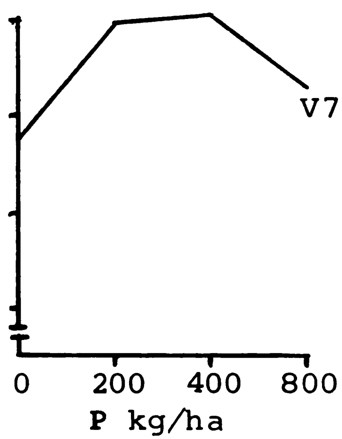


Figure 44

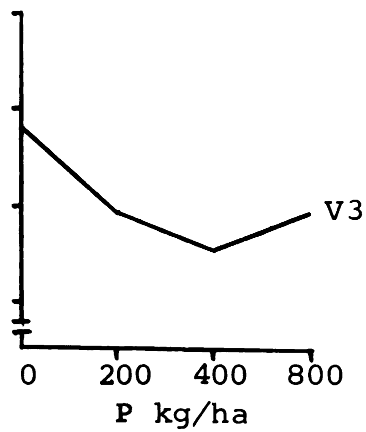


Figure 45

Figures 39-45. Shapes of yield curves with phosphorus treatments.

Internal or external nutrient balances may be upset, promoting a yield decrease. Work by Shellenberger (1970) supports this. This group is not tolerant to supra-optimal P levels.

The third group (Figure 41) shows little yield change with the first P increment, but with the second a large yield increase is realized. The third increment produced a sharp decrease. These varieties may be far from their optimum P level at P zero. The first increment isn't enough to evoke a yield change. The second increment brings it nearer its optimum. The great decrease with the third increment may again indicate supra-optimal P levels.

The fourth group (Figure 42) shows relatively little change across the P levels. The optimum P level may be present prior to the P increments. This variety also appears to be tolerant of high P levels. Another possibility is that sufficiently high P levels were not employed so as to evoke a yield change. This is doubtful, since large increments of P were utilized.

The fifth group (Figure 43) shows little change with the first increment, but then increases with the subsequent two increments. Their highest yield was at the highest P level. These varieties apparently needed a higher level of P in the substrate to approach their yield optima than do the other varieties observed thus far.

The sixth group (Figure 49) shows a large increase with the first P increment, little change with the second, and a large decrease with the third. The first increment may permit it to approach its yield optimum at the same time it demonstrates some tolerance to supra-optimal P levels. Plants possess ranges of intricate nutrient balances, rather than specific points, for their optimum performance. The second increment may still be within the optimum balance range, however, the third increment exceeds this range, causing a yield decrease.

The seventh group (Figure 45) shows a decrease with the first two increments of P, and a slight increase with the third. At P zero, it is probably nearer its optimum range, and additional increments upset the internal balance, causing a yield decrease.

Varieties respond differentially to the P increments. This makes it very difficult to predict response. The lack of predictability complicates the determination of the optimum P level for a given variety, and recommending the proper variety, to optimize yield at a given P level. Yield curves should be known for all of the recommended varieties so that varieties and fertility regimes can be matched to maximize yield.

A wide range of adaptability may be of special importance where a variety is expected to be used over a wide range of fertility levels. The variability in fertility available to the plant could be a result of different levels of native soil fertility and/or differences among the farmers' fertilizer practices.

Hydroponics Experiment

The P levels in the hydroponics experiment affected significantly the P and K concentration in the tissue, but not the Ca and Mg concentration (Table 7).

As P levels in the nutrient solution increased, the P concentrations in the plant at first decreased and then increased markedly (Figure 46). At the lowest level of P, growth was greatly inhibited. The P absorbed at the lowest level was probably not being utilized in growth, permitting a moderate accumulation of P. With the next two increments growth was stimulated, but the P concentration in the tissue decreased. The decrease may be due to growth dilution. The last P increments produce a general increase in P concentrations in the tissue.

K concentrations in the tissue increase as P levels in the nutrient solution were raised to 14 ppm (Figure 47). Above that P level, K concentrations in the tissue decrease. The initial increase in K concentration may be due to more favorable growing conditions provided by increased levels of P. Again, the decrease in K may be a result of growth dilution at high P levels.

The ability of different varieties to concentrate P, K, Ca and Mg, were observed (Figures 48-51). Variety 2 which was the highest in P concentration, was relatively low in K, Ca, and Mg. Variety 1 was high in K and Ca, but low in P and Mg. Variety 3 was moderately high in all of the cations studied, but low in P. Variety 4 was very high in K,

Table 7. Summary table for the analyses of variance for the Hydroponics Experiment at Turrialba, Costa Rica (1968)

		Mean Squares			
Source	d.f.	Phosphorus	Potassium	Calcium	Magnesium
Reps. (R)	2	16,805,735 N.S.	199,368,670 N.S.	139,310,186 N.S.	6,851,413 N.S.
Phos. (P)	6	75,901,543**	2,122,783,489**	100,415,309 N.S.	8,547,384 N.S.
Error a	12	6,448,762	169,447,232	36,021,585	4,176,227
Var. (V)	3	45,435,385**	2,015,700,883**	129,948,011**	6,956,947**
P x V	18	4,437,307 N.S.	313,046,884**	30,151,905**	1,570,123 N.S.
Error b	42	3,781,434	133,450,753	12,844,111	983,649
Plant Parts (PP)	2	348,787,764**	17,049,042,422**	7,984,882,656**	278,882,417**
P x PP	12	18,455,524**	1,020,690,823**	26,926,522**	3,726,608**
V x PP	6	18,874,812**	587,942,284**	214,520,641**	4,419,439**
P x V x PP	36	2,447,983 N.S.	123,547,611**	19,747,582 N.S.	1,458,791 N.S.
Error c	112	2,245,216	68,629,587	13,643,112	1,380,258

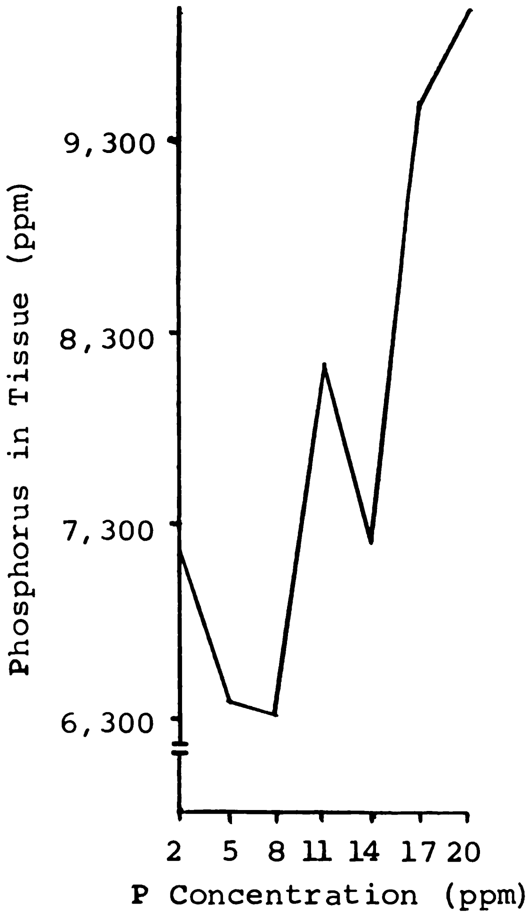


Figure 46

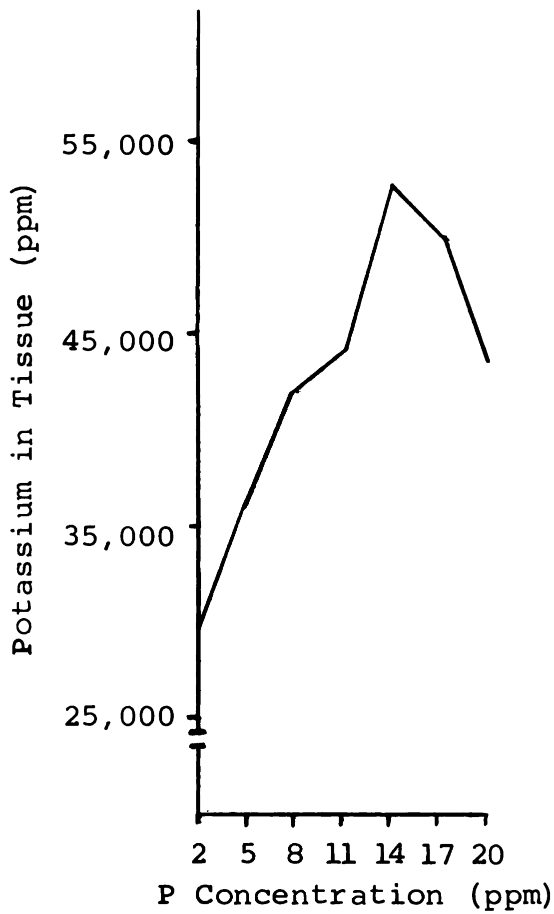


Figure 47

Figures 46-47. Phosphorus and potassium concentrations in the plant at various phosphorus levels.

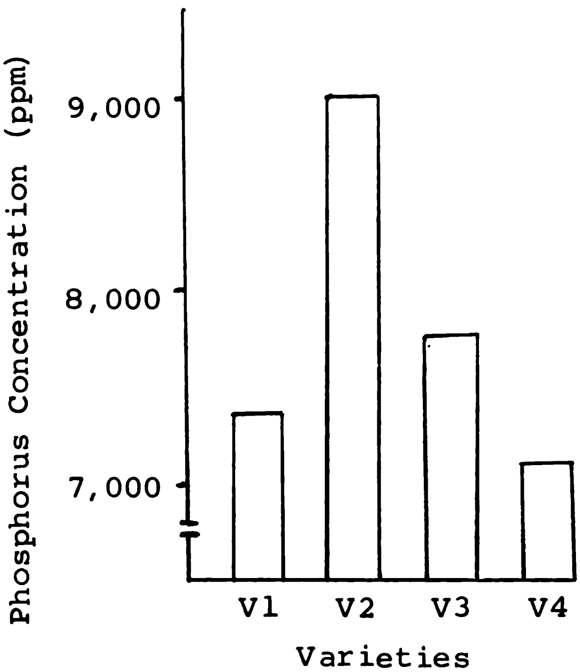


Figure 48

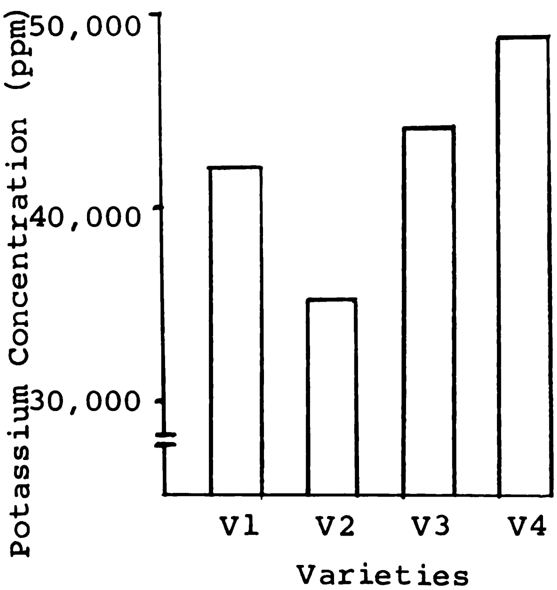


Figure 49

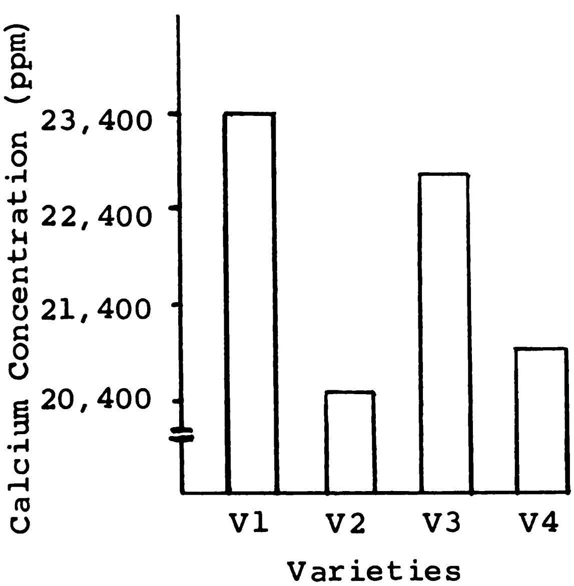


Figure 50

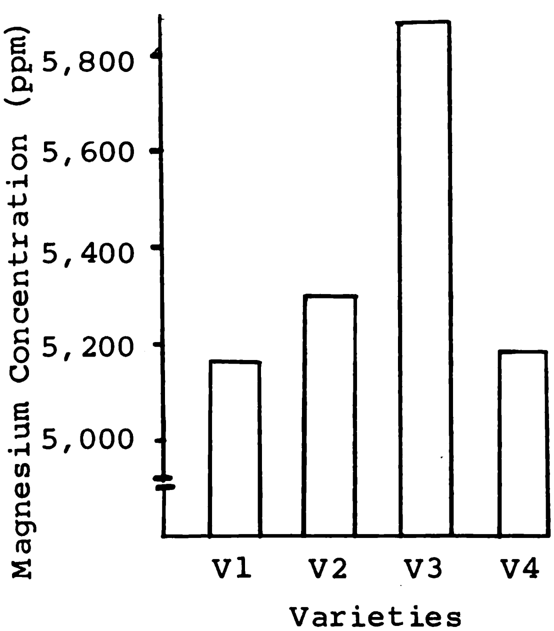


Figure 51

Figures 48-51. Varietal differences in the concentration of P, K, Ca, and Mg in the whole plant.

but low for P, Ca, and Mg. These results are probably reflections of genotypic differences in ability to concentrate the elements studied. Each of the 4 varieties studied demonstrated a different pattern of accumulation.

Phosphorus x variety (PxV) interactions were present for K and Ca concentrations, but not for P and Mg. Figures 52 and 53 show the interactions graphically. In the varieties under study, the P levels in the nutrient solution affected the Ca and K concentrations differently, but the P and Mg concentrations were affected quite uniformly in all varieties. It is interesting to note from Figures 52 and 53 that significant varietal interaction occurs only over certain P intervals. In looking for differential ability to concentrate an element, it is necessary to know at which concentrations the varieties can be differentiated. The interval over which differentiation occurs may be specific to a given combination of varieties.

The differential influence of substrate concentration of one element on the accumulation of another element is demonstrated by the differential effect P levels have on K and Ca concentrations. This could be partially due to differential growth response of varieties to P.

Figures 54-57 illustrate the significant differences among plant parts for all of the elements studied. The leaves and roots are relatively high in P, Ca, and Mg, when compared to the stems. This might be expected since they are sites of much metabolic activity. The highest K levels

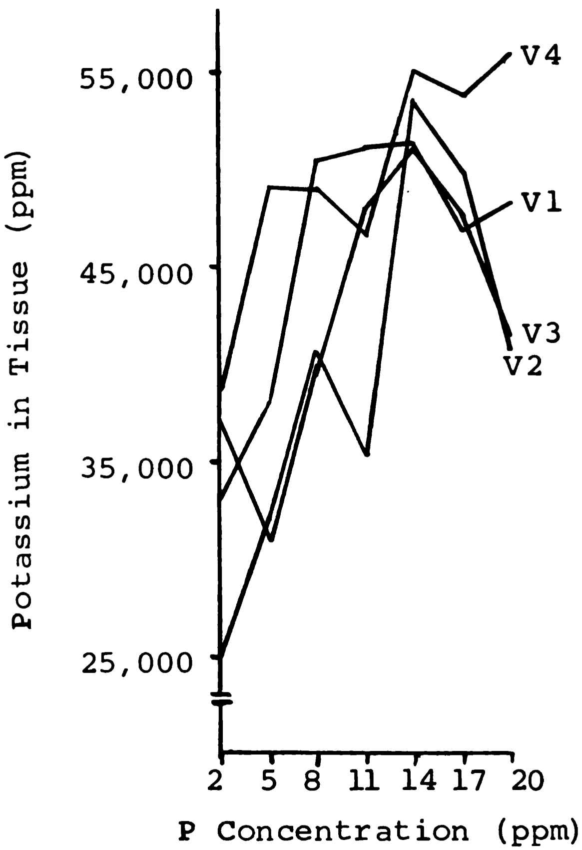


Figure 52

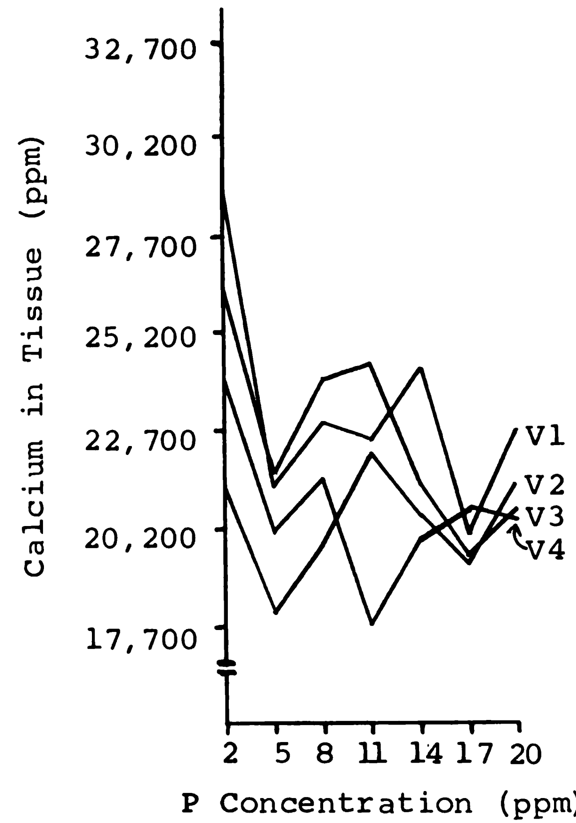


Figure 53

Figures 52-53. Phosphorus x variety interactions for K and Ca concentrations.

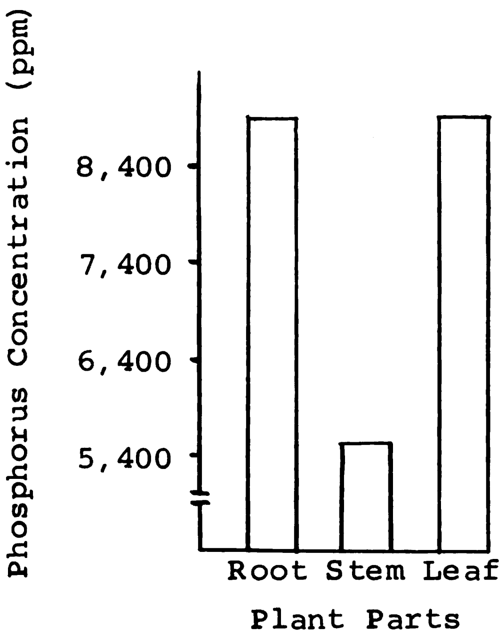


Figure 54

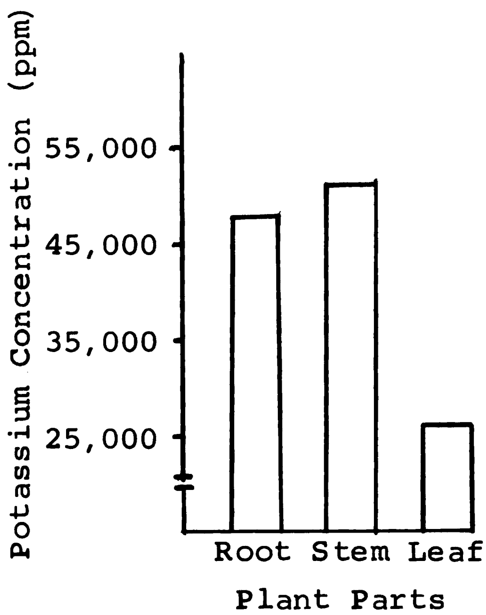


Figure 55

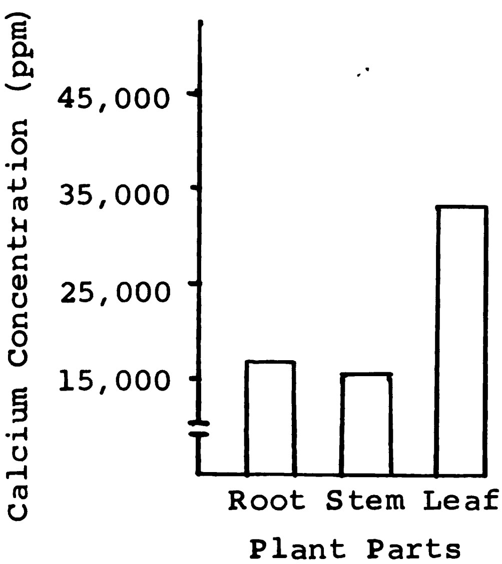


Figure 56

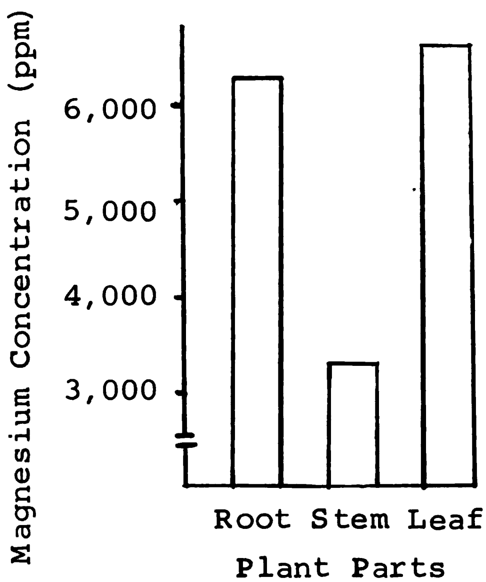


Figure 57

Figures 54-57. Concentrations of P, K, Ca, and Mg in the roots, stems, and leaves.

are found in the stem. A possible explanation is that proportionately more growth occurred in the leaves promoting a dilution effect.

The phosphorus x plant part (PxPP) interaction was significant for all of the elements (Figures 58-61). In Figure 58 increased P at the higher levels produced a much greater P concentration in the root than in any other part.

Figure 59 shows that most of the increase in K with P increments occurred in the stem as compared to the roots and leaves, which were more or less constant across P levels. Proportionately less growth may have occurred in the stem as the P levels were increased, causing an apparent increase in K accumulation.

Figure 60 shows Ca levels remaining quite constant for the plant parts over P levels, with exception to the leaf x root interaction over the 8-11 ppm interval.

In Figure 61 the plant parts show somewhat similar curves for Mg concentration with the exception of the leaf x root interaction over the 8-11 and 14-17 ppm interval.

Figures 62-65 show the variety x plant part interactions. In Figure 62 it can be seen that varieties 1 and 3 show less relative concentrations of P in the stems as compared to the roots, while 2 and 4 show larger relative concentrations in the stem as compared to the roots. Variety 2 shows relatively less P in the leaves, as compared to the stems, than do the other varieties.

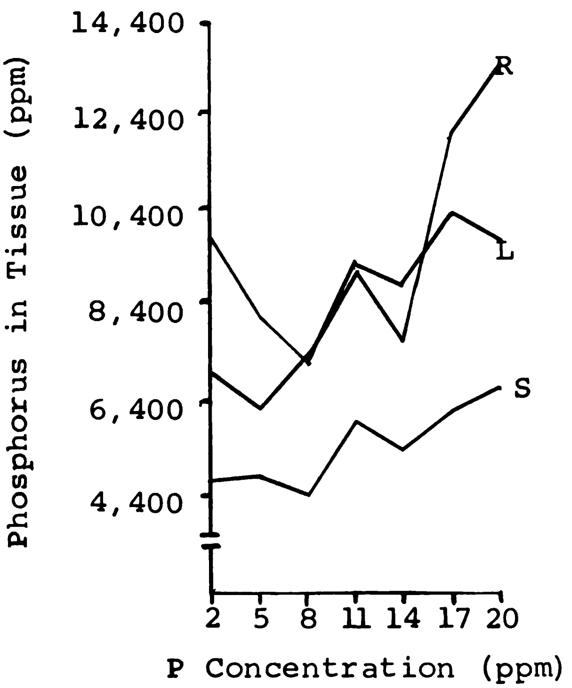


Figure 58

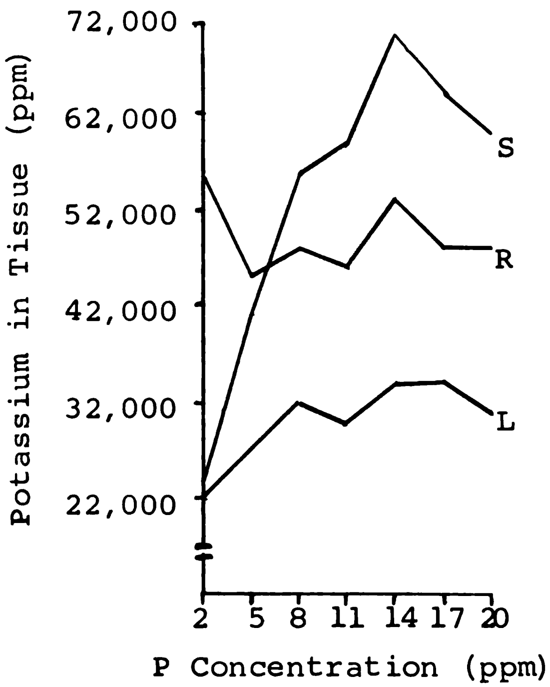


Figure 59

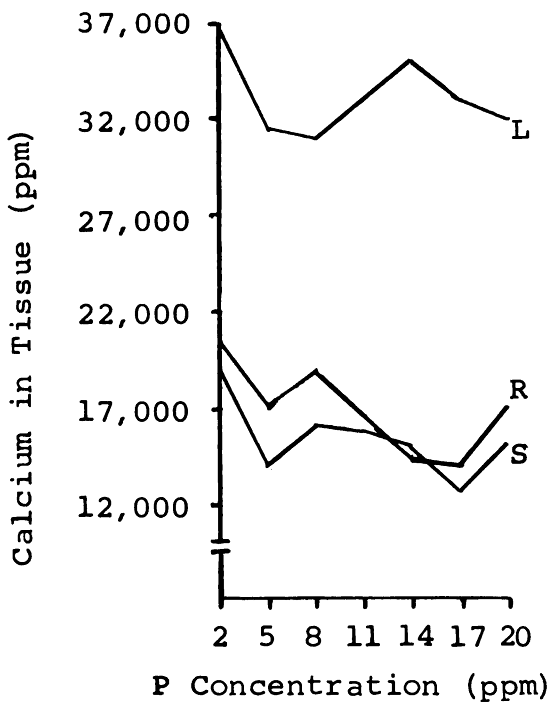


Figure 60

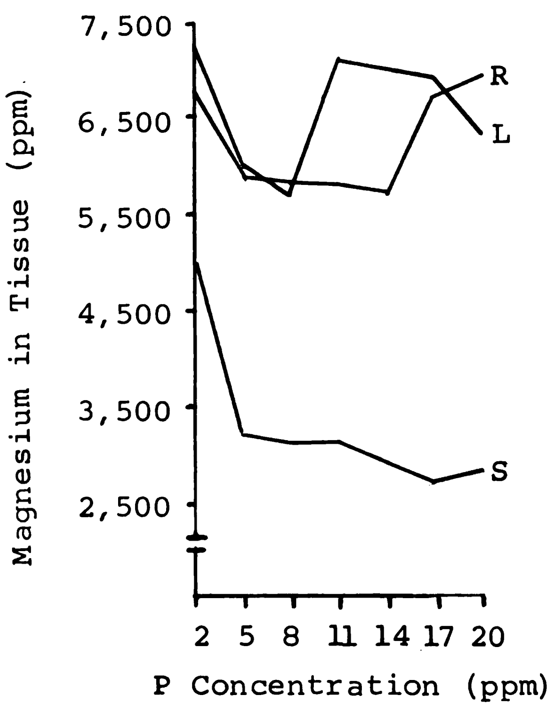


Figure 61

Figures 58-61. Phosphorus x plant parts interaction for P, K, Ca, and Mg concentrations.

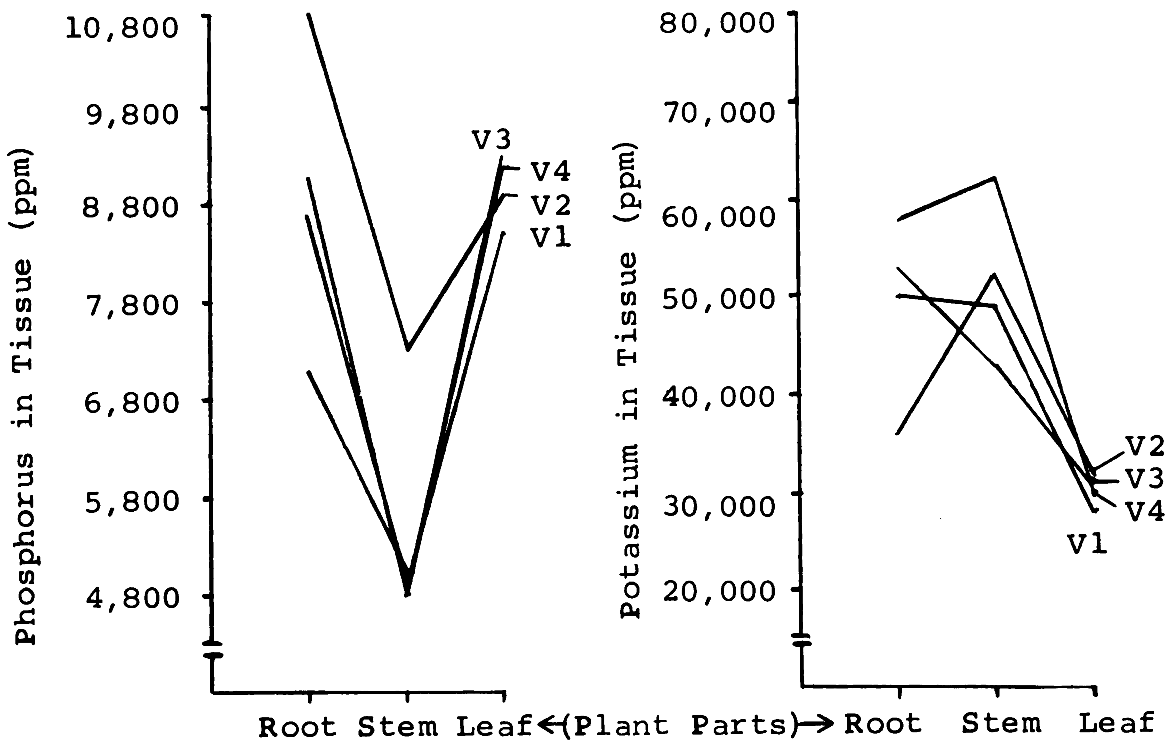


Figure 62

Figure 63

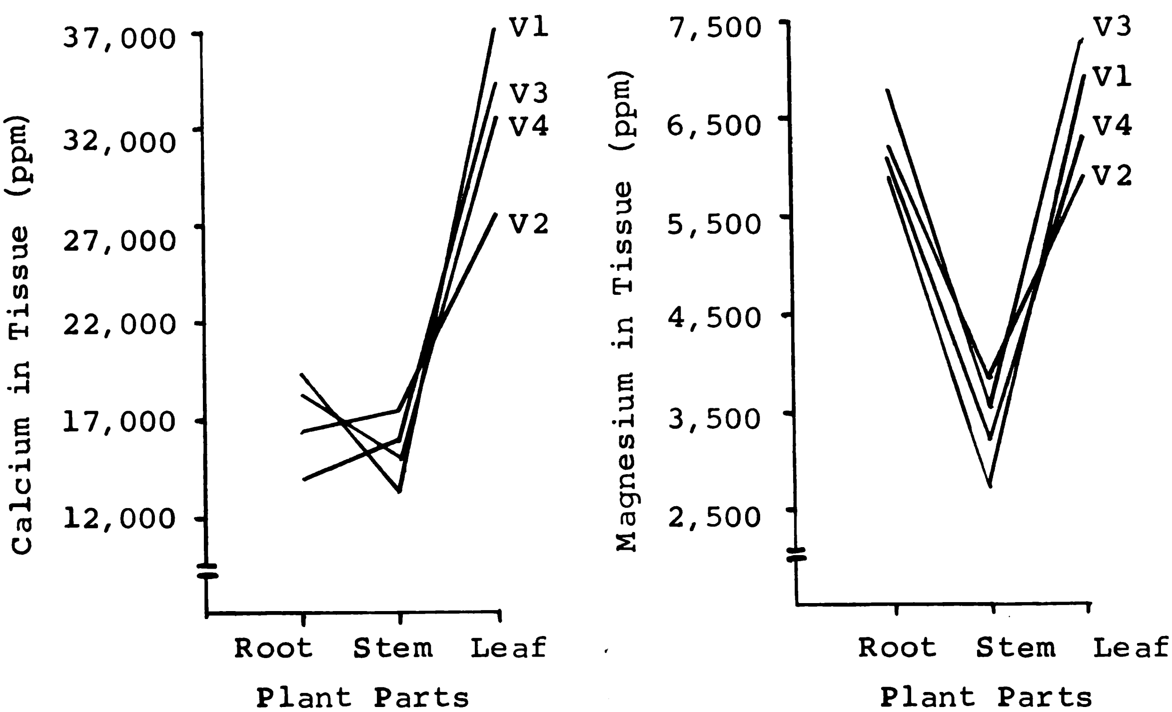


Figure 64

Figure 65

Figures 62-65. Variety x plant part interaction for P, K, Ca, and Mg.

In Figure 63 varieties 2 and 4 show relatively greater concentrations of K in the stems, as compared to the roots, than do varieties 1 and 3. Variety 4 shows a relatively lower concentration in the leaves, as compared to the stem, than do the other varieties.

Figure 64 shows varieties 1 and 3 with a relatively lower concentration of Ca in the stems, as compared to the root, than do varieties 2 and 4. Variety 2 shows relatively less Ca in the leaves, as compared to the stems, than do varieties 1, 3, and 4.

In Figure 65 all of the varieties show relatively the same Mg concentration in the stems, as compared to the roots. Variety 2 shows relatively less concentration of Mg in the leaves, as compared to the stem, than do varieties 1, 3, and 4.

The variety x plant part interaction may be a result of differential growth in the plant parts. It might also indicate differential ability to translocate nutrients from the root to the stem, and from the stem to the leaves. To differentiate between these two possibilities, the total quality of the elements in the various plant parts (concentration x weight), would have to be known. The concentrations as well as the total quantities of the elements are included in Tables 14-21 in the Appendix. No attempts were made to interpret the data obtained from total quantities, since this was not within the scope of this experiment.

SUMMARY AND CONCLUSION

As a result of the Greenhouse, Field, and Hydroponics Experiments certain answers to the questions formulated in the Introduction were found.

1. The fertilizer increment increased yield and all of the yield components when measured over all varieties (greenhouse results).
2. Number of pods/plant (X) was increased more than Y and Z with added fertilizer increment (greenhouse results).
3. Varieties differed in their yield capacity at a low and high fertility level (T_0 or T_1) indicating differences in efficient use of the substrate (greenhouse results).
4. Varieties responded differentially to added fertilizer for W, X, Y, and Z (greenhouse results).
5. The response values were normally distributed with W and X showing more diversity in response than Y and Z.
6. Response to added fertilizer could not be predicted from knowledge of the values prior to the addition (greenhouse results).

7. High yielders and producers of X under high fertility conditions were generally also high responders for the same characters (greenhouse results).
8. Yield response was accomplished through different combinations of response in X, Y, and Z (greenhouse results).
9. Response, or lack of it, was not specific to either the improved or unimproved varieties (greenhouse results).
10. The nitrogen effect over all varieties was greater than the phosphorus effect (field results).
11. Differential response was more prevalent for phosphorus than for nitrogen (field results).
12. Varieties demonstrated differences in optimum phosphorus levels (field results).
13. Varieties differed in tolerance to sub and supra-optimal levels of phosphorus (field results).
14. Varieties differed in accumulating P, K, Ca, and Mg (hydroponics results).
15. Plant parts differed in accumulating P, K, Ca, and Mg (hydroponics results).
16. Varying the P level in the substrate affected the concentrations of P and also of K in the tissue (hydroponics results).
17. Varieties responded differentially to P levels with respect to K and Ca concentration (hydroponics results).

18. Plant parts responded differentially to P levels with respect to P, K, Ca, and Mg concentrations (hydroponics results).

It is inferred from the results obtained that varieties of beans have unique genetic properties that regulate the pattern of responses to mineral nutrients. The diversity of the response pattern to levels of phosphorus, if these patterns are indeed genetically characteristic of the varieties and not some artifact, suggests a degree of genetically regulated fitness to mineral balances.

Since each of the bean varieties is a component of the ecological system in which it evolved, diversity with respect to patterns of response, must reflect a natural diversity of the soils with respect to levels and balance of minerals. This variability, with respect to the nutrient status of the soil, might be expected since highly variable topographical and climatic conditions along with other factors affecting soil formation exist.

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BIBLIOGRAPHY

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APPENDIX

APPENDIX

Table 8. List of varieties used in the Greenhouse Experiment

Var. No.	Variety Name	Percent Response	Improvement Level	Collection Site
1	1-N	150	Unknown	Costa Rica
2	Mexico 450-N	353	Unknown	Mexico
3	Mex-74-N	170	Unknown	Mexico
4	Mex-73-N	277	Unknown	Mexico
5	Mex-21-N	229	Unknown	Mexico
6	111-N	349	Unknown	Costa Rica
7	61-N	217	Unknown	Costa Rica
8	4-N	392	Unknown	Costa Rica
9	Mex-38-P	118	Unknown	Mexico
10	Tostada Manteca	596	Unimproved	Ecuador
11	S-89A-N	355	Unknown	Costa Rica
12	Sal-219-N	166	Unknown	Salvador
13	Sal-208-N	218	Unknown	Salvador
14	Mex-140-N	169	Unknown	Mexico
15	Mex-74-N Brillante	170	Unknown	Mexico
16	Sal-66-N	249	Unknown	Salvador
17	Frijolnegro Indio	215	Unimproved	Costa Rica
18	Matambre Negro "A"	470	Unknown	Unknown
19	Negro #2 Merc. Puntarenas	134	Unimproved	Costa Rica
20	Negro Costa Rica	219	Unimproved	Costa Rica
21	Negro #1 Chirripo-800m.	238	Unimproved	Costa Rica
22	Ahumado De Chirripo Linea 24	71	Unimproved	Costa Rica
23	5-A Vaina Blanca	112	Unknown	Costa Rica
24	Santa Clara	232	Unknown	Costa Rica
25	Antigua Negro	268	Unknown	Costa Rica
26	Quebradilla Platanil-lo Chirr. 1200m.	104	Unimproved	Costa Rica
27	Carriente Canero	143	Unknown	Unknown
28	33-P	204	Unknown	Costa Rica
29	Mecentral	391	Improved	Mexico
30	Porotos Pacuare	423	Unimproved	Costa Rica

Table 8--Continued

Var. No.	Variety Name	Percent Response	Improvement Level	Collection Site
31	S-237-P	235	Unknown	Unknown
32	Col-92-P	141	Unknown	Unknown
33	Venezuela-22	271	Unknown	Venezuela
34	Col-122-N	324	Unknown	Unknown
35	Col-105-N	220	Unknown	Unknown
36	Col-102-N	250	Unknown	Unknown
37	C-36-N	318	Unknown	Unknown
38	C-163-N	242	Unknown	Unknown
39	Criollo Pacuare 2	164	Unimproved	Costa Rica
40	U.S.A. 56-P	195	Improved	U.S.A.
41	Negro 1 Rio Naranjo Bagaces	250	Unimproved	Costa Rica
42	Negro Los Angeles Canas	103	Unimproved	Costa Rica
43	Negro Corriente Brillante-Pac	191	Unimproved	Costa Rica
44	Negro Stg. Maria de Jesus	373	Unknown	Unknown
45	Flor De Mayo Negro 716-2-5	136	Unknown	Unknown
46	Flor De Mayo Negro Brillante	187	Unknown	Unknown
47	Chimbolo Negro Pej-Perez Zelendos	252	Unimproved	Costa Rica
48	S-64-P	254	Improved	Unknown
49	Negro Nicoyano Platanillo	204	Unimproved	Unknown
50	San Vicente El Salvador	315	Unknown	Salvador
51	Guate-2805-4M-OM	202	Unknown	Guatemala
52	Jamapa	331	Improved	Mexico
53	Rico	192	Improved	Costa Rica
54	Porillo No. 1	148	Improved	El Salvador
55	S-182-N	387	Improved	Costa Rica
56	Black Turtle Soup	293	Improved	U.S.A.
57	H-182-N	422	Improved	Unknown
58	S-19-N	113	Improved	Costa Rica
59	Negro De Venezuela	153	Unknown	Venezuela
60	Col-123-N (Turrialba-2)	411	Improved	Unknown
61	Rinon Oscuro Antigua	833	Unimproved	Guatemala
62	Rojo Antigua	99	Unimproved	Guatemala
63	Seleccion Alto de La Paloma S.I.G.	286	Unimproved	Costa Rica
64	Rojo Chirripo 1200m.	382	Unimproved	Costa Rica
65	Mercado Puntarenas	364	Unimproved	Costa Rica

Table 8--Continued

Var. No.	Variety Name	Percent Response	Improvement Level	Collection Site
66	Chileno De Chirripo	114	Unimproved	Costa Rica
67	Col-112-R	524	Unknown	Unknown
68	37-R	358	Unknown	Unknown
69	Mex-78-R	328	Unknown	Mexico
70	64-P	341	Improved	Costa Rica
71	U.S. Pinto-14	331	Improved	U.S.A.
72	Mexicano (C.N.P.) Pej. Perez Zel.	217	Unimproved	Costa Rica
73	Carnita 1 Rio Naranjo	153	Unimproved	Costa Rica
74	Panamito-B	80	Unimproved	Unknown
75	Rojo Quebradillo Platanillo 1200m.	251	Unimproved	Costa Rica
76	Yainica Yaina Morada S.I.G.	238	Unimproved	Costa Rica
77	Carnita Vere Pacuare	247	Unimproved	Costa Rica
78	S-98-R	108	Unknown	Unknown
79	S-5-R	147	Unknown	Unknown
80	Rosita-1	200	Unknown	Unknown
81	Chimbolo Rojo San Roque De Nicoya Cuenca Del Rio Oro	284	Unimproved	Costa Rica
82	Rojo Grande Cartago	96	Unimproved	Costa Rica
83	S-204-B1	309	Unknown	Unknown
84	Carne-5	161	Unimproved	Costa Rica
85	Rojo San Isidro Gen.	127	Unimproved	Costa Rica
86	Mexico-80-R	30	Improved	Costa Rica
87	Col-1-63A	217	Improved	Honduras
88	PI-163-372	555	Unknown	Peru
89	Dark Red Kidney	212	Improved	U.S.A.
90	U.S.A.-2-R	185	Improved	U.S.A.
91	Ahumados-Alto De Las Yaras	241	Unimproved	Costa Rica
92	Amarillo De Pacuare	228	Unimproved	Costa Rica
93	Tres En Uno Legitimo 1100m.	229	Unimproved	Costa Rica
94	Chichicastenango 1800-2200m.	144	Unimproved	Guatemala
95	Ahu. Chirripo 800m.	509	Unimproved	Costa Rica
96	Mercado De Puntarenas	331	Unimproved	Costa Rica
97	Matambre Amarillo "A"	158	Unknown	Unknown
98	Frijol Leche Pej. Per. Zeledon	341	Unimproved	Costa Rica
99	Bayo San Isidro General	91	Unimproved	Costa Rica
100	Matambre	138	Unimproved	Ecuador

Table 8--Continued

Var. No.	Variety Name	Percent Response	Improvement Level	Collection Site
101	Blanco Parramos	248	Unimproved	Guatemala
102	Mat-2-B	118	Unimproved	Nicaragua
103	Col-119-Bl	117	Improved	Unknown
104	S-124-B	199	Unknown	Unknown
105	S-560-R	286	Unknown	Unknown
106	U.S.A. 12-Bl	432	Improved	U.S.A.
107	Jin-11-B	39	Unimproved	Nicaragua
108	S-324-B	521	Unknown	Unknown
109	Seaway	303	Improved	U.S.A.
110	Bayo Mercado Cartago	158	Unimproved	Costa Rica
111	18-B	168	Unknown	Unknown
112	Saginaw	155	Improved	U.S.A.
113	Perry Marrow	300	Improved	U.S.A.
114	Poroto Eterno	152	Unknown	Ecuador
115	19-B	394	Unknown	Unknown
116	45-B	227	Unknown	Unknown
117	30-A	129	Unknown	Unknown
118	S-719-Bl	141	Unknown	Unknown
119	S-856-B-10	331	Improved	Unknown
120	Bayomex	239	Improved	Mexico
121	Valiente "B"	182	Unimproved	Costa Rica
122	Canario-101	329	Improved	Mexico
123	46-P	88	Unknown	Costa Rica
124	S-64-P	299	Unknown	Unknown

Table 9. Soil test results

						meq/100 g soil			% Base
Soil	pH*	%N	P (kg/ha)	% O.M.	CEC	K	Ca	Mg	Sat.
Pacuare	6.5	0.291	12.04	4.85	29.93	1.39	21.61	2.63	85.6
Pacuare-B	6.4	0.754	45.50	13.10	39.69	1.20	30.50	6.33	95.8
Alajuela	5.2	0.222	3.26	4.80	24.60	1.02	4.59	1.50	28.9
Turrialba	5.7	0.329	2.24	6.10	26.68	0.92	7.39	1.43	36.5

*1:1 soil to H_2O ratio.

Table 10. Varieties used in the Field Experiment

Field No.	Greenhouse Number	Variety Name
1	66	Chileno De Chirripo
2	2	Mexico-450-N
3	94	Chichicastenango 1800-2200 mts.
4	107	Jin-11-B
5	9	Mex-38-P
6	123	46-P
7	74	Panamito-B
8	42	Negro-Los Angeles Cañas
9	100	Matambre
10	102	Mat-2-B
11	30	Porotos Pacuare
12	62	Rojo Antigua
13	73	Carnita 1 Rio Naranjo Bagaces
14	16	Sal-66-N
15	25	Antigua Negro
16	106	U.S.A.-B1

Table 11. Statistics for yield and the yield components at low and high fertility

Statistic	Yield and the Yield Components							
	WT_0	WT_1	XT_0	XT_1	YT_0	YT_1	ZT_0	ZT_1
Mean	4.71	14.17	4.55	10.72	4.14	4.83	26.22	28.74
Std. dev.	1.83	3.83	1.47	3.06	0.83	0.80	10.40	9.00
$LSD_{.05}$	2.93	6.12	2.35	4.90	1.32	1.28	16.66	14.40

Table 12. Summary table of response values for X, Y, Z, and W

Entry	X	Y	Z	W	Entry	X	Y	Z	W
1	+8.05*	-2.44*	-00.31	-1.79	30	+2.72	+0.03	-01.96	+5.33*
2	+1.39	+0.10	+00.79	+0.67	31	-0.73	+0.11	+02.04	+4.38
3	+1.60	-0.37	-00.70	+2.05	32	-4.28*	+0.38	+07.91*	-5.13*
4	+4.16*	-0.07	+01.47	+6.02*	33	+0.28	+0.40	-01.81	-0.94
5	-3.28	-0.16	-01.13	-4.54	34	+2.27	+0.15	-00.24	+6.50*
6	+3.05	+0.20	+02.77	+6.28*	35	+0.16	+0.49	-03.23	+0.51
7	+2.60	+0.23	+00.63	+3.64	36	-0.39	+0.07	-02.04	-1.30
8	+4.39*	-0.78	+00.03	+1.43	37	+3.60*	+0.49	-04.08	+1.47
9	-1.06	-0.15	-02.70	-0.64	38	-0.39	+0.36	+02.40	-2.56
10	+0.39	+0.66	+01.95	+4.63	39	-0.39	-0.70	+05.01	0.00
11	-2.95	+0.27	+00.30	-4.14	40	-3.73	-0.29	+07.24	-4.26
12	-1.06	+0.13	-04.00	-0.87	41	-1.06	-0.18	+00.40	-1.29
13	-0.84	-0.04	+02.10	-0.61	42	-0.62	-0.47	-02.48	-2.94
14	-2.28	-0.33	+00.94	-3.79	43	+3.06	-0.39	+01.07	+3.73
15	+1.05	-0.21	+03.04	+3.70	44	+0.05	-0.06	-01.81	+2.15
16	-0.95	+0.61	+01.61	+1.82	45	-0.50	-0.09	-05.32	+0.51
17	-1.72	-0.09	-00.69	-1.89	46	+2.38	-1.16*	+00.26	+1.33
18	+3.83*	+0.57	-00.73	+4.71	47	+3.38	-0.40	-02.94	+1.03
19	-1.05	-0.28	+03.09	+0.10	48	+0.39	-0.41	+01.53	+2.56
20	+0.72	+0.56	+01.04	+1.59	49	+0.72	+0.52	+01.53	+3.97
21	+0.50	+0.72	+00.03	+1.57	50	+2.94	-0.07	+02.64	+2.75
22	-3.51	-0.11	-01.87	-6.54*	51	+1.83	+0.12	-03.23	+0.67
23	-2.61	+0.46	-01.11	-2.71	52	+2.49	+0.65	-04.83	+1.92
24	+1.27	+0.14	-01.02	+0.83	53	+2.50	-0.47	+00.40	+2.14
25	+0.61	-0.34	-01.17	0.00	54	-2.17	+0.57	-00.79	-1.19
26	-3.39	+0.44	+00.17	-3.61	55	+1.27	+0.99*	+01.76	+1.65
27	-2.84	+0.30	-01.96	-2.58	56	+1.38	-0.07	+05.34	+1.05
28	-2.39	+0.31	-03.91	-5.04*	57	+0.72	+0.87*	-01.38	+0.80
29	-4.39*	-0.01	+04.16	-2.60	58	+1.61	-0.53	+01.04	-0.73

Table 12--Continued

Entry	X	Y	Z	W	Entry	X	Y	Z	W
59	+1.38	-0.30	-02.15	+0.74	88	+0.72	+0.06	+05.59	-0.77
60	+2.05	+0.47	-00.26	+2.03	89	-4.39*	-0.09	-02.64	-5.95*
61	-0.94	+0.43	+06.49	+1.63	90	-3.84*	-0.26	-02.13	-6.28*
62	-2.94	-1.81*	+00.68	-4.37	91	-0.94	+0.61	+02.24	+0.97
63	+1.28	+0.72	-04.72	+1.53	92	-0.28	+0.55	-00.34	-2.75
64	+0.94	+0.92*	-05.04	+4.91*	93	+2.16	-0.27	-00.40	+0.15
65	+0.05	+0.81	+01.80	-0.49	94	+0.83	-0.47	+01.09	+3.94
66	-1.50	+0.22	-01.62	+0.61	95	+1.83	-0.49	+03.55	+2.30
67	-4.06*	+0.53	+08.67*	-5.15*	96	+6.61*	-0.78	+00.80	+1.43
68	-0.50	+0.16	-04.31	-0.08	97	-1.40	-0.03	-00.73	+0.92
69	+2.83	+0.14	-00.93	+4.80	98	+4.05*	+0.52	+01.36	+3.94
70	-1.17	+1.24*	+05.12	+4.76	99	-2.17	+0.19	-01.88	-2.36
71	-1.28	-0.46	+03.20	-2.06	100	+1.72	-0.65	+02.42	+1.88
72	+0.05	-0.08	+01.85	+0.74	101	+2.83	+0.05	+00.52	+2.67
73	-4.06*	+1.18*	-00.09	-5.32*	102	+0.28	-0.64	-02.05	-1.97
74	-1.06	-0.70	-01.33	-1.96	103	-3.72*	+0.01	+09.93*	-5.59*
75	-0.28	+0.02	+06.07	+4.48	104	+2.83	-0.65	+01.15	+1.75
76	-1.84	-0.15	+05.80	-0.09	105	+2.72	-0.05	+05.81	+3.22
77	+1.83	-0.63	-01.53	-0.41	106	+4.06*	+0.25	+02.15	+4.90*
78	-2.17	-0.44	+01.91	-0.86	107	-4.84*	+0.09	-03.48	-6.72*
79	-0.50	-1.03*	+01.56	-0.27	108	+2.05	+0.02	-01.19	+2.34
80	+4.05*	-0.35	-01.41	+2.24	109	+2.39	+0.53	-06.18	-3.09
81	-3.95*	+1.22*	+02.75	-2.81	110	+0.28	+0.23	-03.26	-0.72
82	-2.17	-0.07	-08.62*	+0.11	111	+0.39	-0.48	+02.72	+1.39
83	+1.06	+0.28	+01.96	+0.74	112	-2.06	-0.97*	-01.22	-6.61*
84	-0.61	-0.07	-01.17	-1.73	113	-0.62	-0.67	-34.44*	+2.16
85	-0.73	-1.10*	-04.57	-3.13	114	+0.50	-0.29	+01.50	+1.03
86	-5.62*	+0.21	-02.86	-7.40*	115	-2.06	+0.14	+02.51	-4.32
87	-0.61	-0.61	-04.94	+0.26	116	+1.50	-0.19	+00.08	+3.16

Table 12--Continued

Entry	X	Y	Z	W	Entry	X	Y	Z	W
117	-1.62	+0.13	-00.76	-1.26	121	+0.17	+0.09	-00.98	-0.96
118	-3.39	+0.81	-00.40	-4.78	122	-2.28	-0.02	-00.64	-3.91
119	+0.72	-0.12	+04.95	+3.24	123	-2.95	-0.30	+01.49	-3.26
120	-0.72	-0.94*	-02.23	-1.25	124	-1.95	+0.84	+05.35	+1.05

W	X	Y	Z
$\bar{X} = 0$	$\bar{X} = 0$	$\bar{X} = 0$	$\bar{X} = 0$
$s = 3.16$	$s = 2.55$	$s = 0.57$	$s = 4.37$
$LSD_{.05} = 4.90$	$LSD_{.05} = 3.61$	$LSD_{.05} = 0.96$	$LSD_{.05} = 7.70$

Table 13. Nitrogen and phosphorus effects on yield and the yield components

Yield and Yield Components	Nitrogen (kg/ha)			Phosphorus (kg/ha)			
	0	100	200	0	200	400	800
W	15.50	21.60	22.50	18.10	20.50	21.25	19.80
X	15.50	20.75	21.75	17.30	19.60	20.25	19.80
Y	4.72	4.86	4.74	4.78	4.75	4.77	4.80
Z	21.70	21.75	21.85	22.25	21.85	21.60	21.40

Table 14. Concentrations of phosphorus in the plant tissue (ppm of P)

Plant Part	Variety	Phosphorus Level in the Substrate (ppm) 2	5	8	11	14	17	20	Plant Part Means
Leaf	1	9214	6343	6750	9681	9026	9685	8942	8520
Stem	1	3591	4374	4302	5536	4896	5653	5441	4828
Root	1	5958	6799	8432	9071	7611	9997	13165	8719
Total	1	6254	5839	6495	8096	7178	8445	9183	7356
Leaf	2	8236	9138	6214	9322	9026	10771	9672	8911
Stem	2	5087	7022	6042	8280	6000	8348	10463	7320
Root	2	8321	6992	9171	10545	8776	15251	16540	10799
Total	2	7215	7717	7142	9382	7934	11457	12225	9010
Leaf	3	12291	8303	8119	9993	8293	9108	9711	9403
Stem	3	5485	4708	3349	5618	4421	4748	5083	4773
Root	3	7831	6415	5769	9464	7326	12661	14476	9135
Total	3	8536	6475	5746	8358	6680	8839	9756	7739
Leaf	4	9117	8708	7741	7970	8707	11490	10485	9174
Stem	4	4639	3266	4002	4798	5174	6295	5904	4868
Root	4	5868	4474	5783	7321	7083	9974	9466	7138
Total	4	6541	5483	5842	6696	6988	9253	8618	7095
Leaf	All Varieties	9715	8123	7206	9242	8763	10264	9703	9005
Stem	All Varieties	4701	4843	4424	6058	5123	6261	6723	5447
Root	All Varieties	6995	6170	7289	9100	7699	11971	13412	8948

Table 15. Concentrations of potassium in the plant tissue (ppm of K)

Plant Part	Variety	Phosphorus Level in the Substrate (ppm)							Plant Part Means
		2	5	8	11	14	17	20	
Leaf	1	20969	25021	29293	34962	33647	31021	32689	29657
Stem	1	31833	30108	45865	59099	59867	59721	58004	49214
Root	1	58199	38078	45007	50159	60188	46539	51439	49944
Total	1	37000	31069	40055	48073	51234	45760	47377	41970
Leaf	2	22623	28342	27000	27515	40330	32943	33269	30837
Stem	2	15053	39185	63737	52613	70594	68925	58054	52594
Root	2	38020	29430	31172	26440	49451	47656	31278	36207
Total	2	25232	32319	40636	35523	53458	49841	40867	35138
Leaf	3	22625	25814	40313	27086	29387	38884	26315	30060
Stem	3	18215	38465	49781	70912	68416	58187	52839	43425
Root	3	58912	49959	61376	55855	54738	42312	45453	52658
Total	3	33251	38079	50490	51284	50847	46461	41536	44044
Leaf	4	22637	29236	27829	28891	34689	32751	31729	29680
Stem	4	27065	56901	64323	61710	82882	71747	70399	62147
Root	4	67680	61686	54601	49708	48069	57118	66168	57861
Total	4	39127	49274	48918	46770	55213	53872	56099	48755
Leaf	All Varieties	22214	27103	32478	29614	34513	33900	31001	26348
Stem	All Varieties	23042	41165	55927	61084	70440	64645	59824	53343
Root	All Varieties	55703	44788	48039	45541	53112	48406	48585	47740

Table 16. Concentrations of calcium in the plant tissue (ppm of Ca)

Plant Part	Variety	Phosphorus Level in the Substrate (ppm) 2	5	8	11	14	17	20	Plant Part Means
Leaf	1	44997	31075	32373	38797	39456	35245	37295	37034
Stem	1	18143	10470	14635	13526	15953	10481	12919	13733
Root	1	26244	22395	21545	15241	17605	14685	18075	19399
Total	1	29795	21313	22851	22521	24338	20137	22763	23365
Leaf	2	26471	28003	20058	27615	32547	30756	26793	27464
Stem	2	19898	15184	18843	20668	15990	14219	17670	17496
Root	2	17910	10957	20629	18394	13156	13174	20516	16391
Total	2	21426	18048	19843	22226	20564	19383	21660	20452
Leaf	3	37826	30632	36903	38012	33392	30932	32515	34317
Stem	3	18703	14803	15948	16513	15263	11736	13184	15165
Root	3	21829	20506	19589	20397	15531	15914	16390	18594
Total	3	26119	21980	24147	24974	21395	19527	20696	22691
Leaf	4	36053	36502	34212	28420	33754	35147	31098	33598
Stem	4	19655	15841	16043	13568	14516	14312	17394	15905
Root	4	16200	14235	14189	11107	11300	12766	12600	13200
Total	4	23969	22193	21481	17698	19857	20742	20364	20903
Leaf	All Varieties	36337	31554	30887	33212	34788	33021	31926	33084
Stem	All Varieties	19100	14075	16368	16069	15431	12688	15292	15577
Root	All Varieties	20546	17024	18988	16285	14398	14135	16896	16896

Table 17. Concentrations of magnesium in the plant tissue (ppm of Mg)

Plant Part	Variety	Phosphorus Level in the Substrate (ppm) 2	5	8	11	14	17	20	Plant Part Means
Leaf	1	8633	5123	5724	8081	7377	6491	6835	6895
Stem	1	4805	2368	2434	2486	2884	2015	2028	2717
Root	1	6398	5718	6047	5506	5294	4729	7295	5855
Total	1	6612	4403	4735	5358	5185	4412	5386	5156
Leaf	2	5758	5892	3572	6071	7534	7349	5331	5930
Stem	2	5671	3423	3257	4146	3205	3132	3625	3780
Root	2	6949	5829	6590	5210	6039	6775	6178	6224
Total	2	6126	5048	4473	5142	5593	5752	5045	5314
Leaf	3	7859	6748	7263	8117	6736	7303	7154	7311
Stem	3	5064	3885	3482	3316	2692	3037	2786	3466
Root	3	7552	5985	4778	7372	5854	8211	7949	6814
Total	3	6825	5539	5174	6268	5094	6184	5963	5864
Leaf	4	6755	6302	6243	6041	6423	6255	5840	6266
Stem	4	4991	3197	3133	2650	2756	2763	2827	3188
Root	4	6235	6313	5854	5114	5865	6956	6397	6105
Total	4	5994	5271	5077	4602	5015	5325	5021	5174
Leaf	All Varieties	7251	6016	5701	7078	7018	6850	6290	6603
Stem	All Varieties	5133	3218	3077	3150	2884	2737	2817	3283
Root	All Varieties	6784	5961	5817	5801	5763	6668	6955	6245

Table 18. Total quantities of phosphorus in the plant tissue (mg of P)

Plant Part	Variety	Phosphorus Level in the Substrate (ppm) 2	5	8	11	14	17	20	Plant Part Means
Leaf	1	16.31	20.04	24.29	42.48	49.42	65.06	76.32	41.99
Stem	1	3.20	6.98	8.92	17.21	18.42	28.10	32.99	16.55
Root	1	10.78	10.96	9.81	12.83	15.08	19.17	31.26	15.70
Total	1	10.10	12.65	14.34	24.18	27.64	37.44	46.85	24.74
Leaf	2	4.68	11.53	10.20	11.27	20.15	23.31	12.80	13.42
Stem	2	1.63	3.60	4.34	4.54	6.10	6.91	5.63	4.68
Root	2	4.26	4.60	4.91	5.03	7.76	9.86	8.45	6.41
Total	2	3.52	6.58	6.49	6.95	11.34	13.36	8.96	8.17
Leaf	3	8.90	13.38	20.87	33.92	32.58	29.85	60.90	28.63
Stem	3	1.80	4.08	5.64	9.69	9.31	13.87	18.55	8.99
Root	3	6.88	7.95	9.45	17.51	12.35	34.31	34.29	17.53
Total	3	5.86	8.47	11.99	20.37	18.08	26.01	37.91	18.38
Leaf	4	12.99	14.11	22.74	38.31	24.14	31.45	43.77	26.79
Stem	4	2.93	2.69	6.74	13.16	8.16	9.24	14.69	8.23
Root	4	6.99	4.55	9.31	14.50	6.64	12.09	14.58	9.81
Total	4	7.64	7.12	12.93	21.99	12.98	17.59	24.35	14.94
Leaf	All Varieties	10.72	14.77	19.52	31.49	31.57	37.42	48.45	27.71
Stem	All Varieties	2.39	4.34	6.41	11.15	10.50	14.53	17.97	9.61
Root	All Varieties	7.23	7.01	8.37	12.47	10.46	18.86	22.15	12.36
Phosphorus Treatment Means		6.78	8.71	11.44	18.37	17.51	23.60	29.52	

Table 19. Total quantities of potassium in the plant tissue (mg of K)

Plant Part	Variety	Phosphorus Levels in the Substrate (ppm) 2	5	8	11	14	17	20	Plant Part Means
Leaf	1	37.62	75.27	105.84	153.22	196.13	230.11	289.88	155.44
Stem	1	28.33	55.34	108.79	183.45	233.13	304.65	359.25	181.85
Root	1	105.34	72.38	53.59	68.94	134.94	95.10	129.98	94.33
Total	1	57.10	67.66	89.41	135.20	188.07	209.95	259.70	143.87
Leaf	2	12.29	37.09	45.01	37.34	85.55	70.70	45.91	47.70
Stem	2	4.82	20.62	45.72	36.28	74.81	57.59	33.73	39.08
Root	2	21.49	18.35	17.28	11.87	49.03	31.78	15.93	23.68
Total	2	12.87	25.35	36.00	28.50	69.80	53.36	31.87	36.82
Leaf	3	17.11	41.96	105.37	90.52	115.50	127.91	161.61	94.28
Stem	3	5.95	34.84	86.52	127.02	145.41	168.88	192.14	108.68
Root	3	48.87	62.47	102.51	103.13	89.49	109.90	106.92	89.04
Total	3	23.98	46.43	98.13	106.89	116.80	135.56	153.56	97.34
Leaf	4	31.71	47.24	83.21	159.70	96.14	88.65	138.80	92.21
Stem	4	18.34	47.23	109.46	188.93	131.40	105.20	179.55	111.44
Root	4	84.52	64.43	86.55	130.60	45.28	69.93	104.99	83.76
Total	4	44.86	52.97	93.07	159.74	90.94	87.93	141.12	95.80
Leaf	All Varieties	24.68	50.39	84.86	110.19	123.33	129.34	159.05	97.40
Stem	All Varieties	14.36	39.51	87.62	133.92	146.19	159.08	191.17	110.26
Root	All Varieties	65.06	54.41	64.98	78.63	79.69	76.68	89.46	72.70
Phosphorus Treatment Means		34.70	48.10	79.15	107.58	116.40	121.70	146.56	

Table 20. Total quantities of calcium in the plant tissue (mg of Ca)

Plant Part	Variety	Phosphorus Levels in the Substrate (ppm)							Plant Part Means
		2	5	8	11	14	17	20	
Leaf	1	78.76	100.88	128.00	169.43	212.53	253.02	319.61	178.89
Stem	1	16.15	18.53	31.46	41.65	64.25	56.84	79.04	43.99
Root	1	47.50	41.01	25.59	20.50	39.59	31.88	42.24	35.47
Total	1	47.47	53.47	61.68	77.19	105.45	110.58	146.96	86.12
Leaf	2	15.31	36.66	32.97	37.23	70.20	67.32	39.88	42.79
Stem	2	6.37	8.16	13.64	11.43	17.69	11.60	9.93	11.26
Root	2	9.39	7.79	11.40	8.59	13.06	8.54	10.47	9.89
Total	2	10.36	17.54	19.34	19.08	33.65	29.15	20.09	21.31
Leaf	3	28.51	49.82	95.24	134.35	135.23	102.67	194.56	105.77
Stem	3	6.10	13.13	27.99	31.04	31.71	34.26	46.21	27.21
Root	3	18.58	26.22	32.36	37.58	26.51	39.48	39.12	31.41
Total	3	17.73	29.72	51.86	67.66	64.48	58.80	93.30	54.79
Leaf	4	51.26	59.04	103.01	142.33	93.54	94.21	127.46	95.84
Stem	4	12.87	13.09	27.77	43.71	22.68	20.97	40.68	25.97
Root	4	21.44	14.51	24.03	28.62	10.71	15.44	19.06	19.12
Total	4	28.52	28.88	51.60	71.56	42.31	43.53	62.40	46.97
Leaf	All Varieties	43.46	61.60	89.81	120.83	127.87	126.81	170.38	105.82
Stem	All Varieties	10.37	13.23	25.22	31.99	34.08	30.92	43.96	27.11
Root	All Varieties	24.23	22.38	23.34	23.82	22.46	23.83	27.72	23.97
Phosphorus Treatment Means		26.02	32.40	46.12	58.87	61.47	60.52	80.69	

Table 21. Total quantities of magnesium in the plant tissue (mg of Mg)

Plant Part	Variety	Phosphorus Levels in the Substrate (ppm) 2	5	8	11	14	17	20	Plant Part Means
Leaf	1	15.28	16.66	22.39	35.34	40.12	42.29	60.82	33.27
Stem	1	4.28	4.06	5.35	7.69	11.82	9.94	12.15	7.90
Root	1	11.58	9.35	7.03	7.63	11.17	8.53	17.10	10.34
Total	1	10.38	10.03	11.59	16.88	21.04	20.25	30.03	17.17
Leaf	2	3.34	7.67	5.86	7.96	16.52	15.82	8.00	9.31
Stem	2	1.81	1.83	2.24	2.14	3.56	2.46	2.00	2.29
Root	2	3.62	3.88	3.55	2.47	5.58	4.33	3.26	3.81
Total	2	2.92	4.46	3.88	4.19	8.56	7.53	4.42	5.13
Leaf	3	5.93	11.08	18.65	27.88	27.86	23.78	43.93	22.73
Stem	3	1.65	3.45	6.16	6.04	5.99	8.92	10.05	6.04
Root	3	6.47	7.61	7.83	13.63	9.99	23.82	18.94	12.52
Total	3	4.67	7.38	10.88	15.86	14.62	18.62	24.30	13.76
Leaf	4	9.70	10.19	18.66	29.92	17.72	16.94	24.64	18.25
Stem	4	3.23	2.68	5.22	8.05	4.32	4.21	7.03	4.96
Root	4	7.55	6.20	9.07	12.36	5.51	8.54	9.90	8.45
Total	4	6.83	6.36	10.98	16.78	9.18	9.89	13.86	10.56
Leaf	All Varieties	8.56	11.40	16.39	25.28	25.55	24.70	34.35	20.89
Stem	All Varieties	2.74	3.00	4.74	5.98	6.43	6.38	7.81	5.30
Root	All Varieties	7.31	6.76	6.87	9.02	8.06	11.14	12.30	8.78
Phosphorus Treatment Means		6.20	7.05	9.33	13.43	13.35	14.07	18.15	