RELATIONSHIP BETWEEN THE CHEMICAL COMPOSITION OF CORN LEAVES AND YIELD RESPONSES FROM NITROGEN AND PHOSPHORUS FERTILIZER

by

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I. INTRODUCTION

The primary objective of fertilizer research is more accurate prediction of yield responses to fertilizer for various soil and management conditions. An important part of this process is the determination of yield response equations so that economic analyses can be applied to the agronomic data. From these analyses, profitable ratios and rates of fertilizer may be determined for given nutrient/nutrient and fertilizer/crop price ratios. Response equations or functions can be determined on only a sample of the fields in the state; predictions for all soils then must be based on the relationship between yield responses to fertilizer and soil tests on the relatively few fertilizer experiments. Therefore, much of the effort in the past towards improving these predictions has been directed towards getting more information about response equations, improving soil test procedures and calibrating soil tests with yield responses to fertilizer.

Another method which has been proposed to test the availability of the nutrients in the soil for prediction of yield responses to fertilizer is that of chemical analysis of the crop. This method involves analyzing either the whole plant or a part of the plant to determine its chemical composition. From fertilizer experiments, the influence of fertilizer treatments on the chemical composition and the relationship between responses and initial nutrient levels in the plants

may be determined. Plant composition has been used widely to determine the availability of nutrients in the soil in nutrient uptake studies, to interpret the results of greenhouse and field experiments and to determine "critical" nutrient levels which are the nutrient percentages in the plant above which little or no yield response occurs from further increase in composition. However, little has been done in correlating yield responses to fertilizer with the nutrient levels below the "critical" levels in the plant and using plant composition directly as a basis to predict these responses.

Using plant analysis to predict yield responses requires a knowledge of the interrelationships among soil fertility, fertilizer rates, chemical composition of the plants and yields or yield responses. To study these relationships in corn, the nitrogen, phosphorus and potassium percentages were determined in corn leaves from a large number of fertilizer experiments. All of the experiments had a phosphorus fertilizer variable, most had a nitrogen variable and many also had a potassium variable. Only the nitrogen and phosphorus fertilizer effects and nitrogen and phosphorus leaf analyses are being used in the main part of this study. Although phosphorus relationships are of most interest, previous research shows clearly that yield responses to phosphorus and phosphorus concentrations in corn plants are highly correlated with associated nitrogen levels. Therefore, the effects of both nutrients on

yield responses and leaf composition will have to be studied simultaneously.

From the effects of nitrogen and phosphorus fertilizers on yield responses and on the nitrogen and phosphorus composition of corn leaves from the same experiments, it is possible to determine the relationship between the responses and leaf composition. The purposes of this study are: (1) to determine the relationships of nitrogen and phosphorus fertilizers and other factors to the phosphorus percentage in corn leaves and (2) to determine the relationships of nitrogen and phosphorus fertilizers, nitrogen and phosphorus composition of corn leaves and other factors to both the yield responses to fertilizer and total yields. Multiple curvilinear regression techniques are used to characterize these relationships quantitatively.

From the relationships derived, leaf analysis and soil tests can be compared to determine which method gives the better prediction of yield responses to fertilizer under Iowa conditions. If leaf analysis gives more information than soil tests, economic analysis of the response equations then can be used to determine most profitable fertilizer rates for any level of nitrogen and phosphorus in corn leaves.

II. REVIEW OF LITERATURE

A. Early History of Plant Analysis

In an excellent review of the literature on plant analysis, Goodall and Gregory (32) report that plant analysis was first proposed by von Liebig in 1840 in his "Law of Restitution". This "Law" required that nutrients should be returned to the soil in amounts equal to those removed by crops. Using plant analysis as an index of available nutrients was apparently first proposed by Weinhold in 1862. Although Weinhold failed to prove his hypothesis of a relationship between plant growth and composition, they report that Hellriegel in 1867 observed that the K[1] content of barley grain and straw increased as K fertilizer was added to a sand culture. He suggested that plant analysis might provide a better index of available nutrients in the soil than soil analysis.

Goodall and Gregory (32) report that much research on plant analysis was done in Europe prior to 1920. Some of the most important was done by Atterberg, Remy and Pfeiffer. These reviewers pointed out that much of the early work has been almost forgotten probably because most of it was done in

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[1]Throughout the rest of the discussion, N, P and K will be used to designate nitrogen, phosphorus and potassium, respectively. Other chemical elements also will be designated by their chemical symbols.

German-speaking countries. Although this earlier work rested upon inadequate experimental foundation and lacked modern statistical techniques, some experiments will compare well with recent work.

B. Application of Plant Analysis for Diagnostic Purposes

Most of the research on plant analysis since 1920 has been done in English-speaking countries according to Goodall and Gregory (32). The expansion was due to increased recognition of trace mineral deficiencies, more attention to horticultural crops whose deficiencies can be recognized and more easily remedied, improvements in analytical techniques and abandonment of plant analysis as a biological method of soil analysis and consideration of it as a means of studying the nutritional condition of the plant itself.

Most of the developments in plant analysis in the past 25 to 35 years have been in diagnostic use. Goodall and Gregory (32) grouped these developments as follows: (1) investigation of nutritional disorders shown by symptoms, (2) interpretation of the results of field trials, (3) development of rapid testing methods for advisory work and (4) use in nutritional surveys.

Plant analysis has helped to identify and classify many deficiency symptoms of various plants.

Plant analysis has been used widely in the interpretation of results of fertilizer experiments (excluding determinations of nutrient uptake for calculating the proportion of added fertilizer absorbed by plants since these experiments deviated from the practice of using the concentration of the nutrients in plant material as an index). First among these investigators were those of the "foliar diagnosis" school, Lagatu and Maume in France and later Thomas and Mack in Pennsylvania. They took samples from a strictly defined morphological position and paid more attention to the ratio than to the actual percentage of the nutrients. They regarded their method as a tool of interpretation and very few examples of their practical application in the field were published.

Thomas and Mack (77) stressed two concepts, that of quantity or intensity of nutrition and that of quality or physiological ratios of the elements. Intensity was the sum of the N, P_2O_5 and K_2O percentages. The latter was expressed as an NPK unit, a ratio calculated from the fraction of each to the total sum after converting percentages to milliequivalents. In the NPK factorial experiment on corn, they felt that the highest yielding treatments thus showed the best balance as shown on their trilinear coordinates. The NPK unit calculated from Tyner's (81) critical levels was far from their "balanced" ratios when graphed in their triangle. The quantity and quality aspects have little value compared to a knowledge of crit-

ical levels. Both values were unduly influenced by luxury consumption of K and too little weight was given to P_2O_5 values whose absolute percentages are much less than those of N or K.

A few other workers adopted the ideas of the "foliar diagnosis" school but soon abandoned the system of trilinear coordinates and used actual percentages.

Many workers have used another diagnostic concept in interpreting field experiments. This has involved the determination of a "critical percentage", defined by Macy (52) to be the nutrient percentage in the plant above which little additional yield increase occurs from further increase in the composition by fertilization.

Ulrich (84, 86, 87) has established critical levels or percentages in various crops such as ladino clover and alfalfa. He pointed out that this information might explain failures to get responses to fertilizer, detect other limiting nutrients and determine if rates were sufficient to give maximum yields. Many others who have determined critical levels of one or more nutrients have included Tyner (81), Bennett et al. (4) and Viets et al. (91) for corn, Seay et al. (69) and Chandler et al. (12) for alfalfa, Lundegårdh (49) for oats and small grains, Clements (18, 19) and Borden (7, 8) for sugar cane and numerous investigators for horticultural crops.

Another group has used rapid chemical analyses, often called tissue tests, for diagnostic purposes. These have been used in advisory work and in the interpretation of results from fertilizer experiments. Plant sap or an extract of fresh material mostly from the conducting tissues was used for analysis. Since the estimated fractions were unassimilated materials which had recently entered the plant, the theory was that their concentration represented the current rate of nutrient uptake.

The tests most widely used were developed at Purdue University by Thornton et al. (78) and used mostly with corn. The tests are roughly quantitative and are reported only in four or five levels. Earlier workers have used expressed or exuded sap to characterize crop nutrition and availability of nutrients in the soil but these methods had practical limitations and were little used. Other tests have used plant sap on chemically-treated paper with the results determined colorimetrically. They have been used widely but have been only roughly quantitative.

The last group of investigations had the primary purpose of describing soil conditions affecting the plant and not directly the nutritional status of the plants analyzed. Surveys have been made for I, Se, Co, and Cu contents of plants, primarily for animal nutrition. From fertilizer trials on forest trees, Mitchell and Chandler (54) were able to develop

leaf analysis to survey nutrient status of forest soils, particularly of nitrogen. Others have used leaf samples from fruit trees and other perennial horticultural crops to survey the status of the major nutrients and trace minerals. Critical nutrient levels were known in some cases but in others they could be estimated by correlating nutrient contents with approximate yields.

C. Application of Plant Analysis for Prediction of Yield Responses to Fertilizer

Much of the research on plant analysis used for diagnostic work has been fragmentary. Although promising initially, most of it fell far short of reaching the objectives of soil fertility research. As Goodall and Gregory (32) pointed out, a qualitative diagnosis of nutrient deficiency, a conclusion that the crop yield probably will or will not be increased by fertilization, is not adequate in practice. What the farmer requires of any method for estimating fertilizer requirements is a prediction of the increase in value of the crop which may be expected from any one of a large range of possible fertilizer treatments. From such predictions, it is possible then to compute what treatment at the expected fertilizer/crop price ratio will likely give the best return. The provision of such predictions, recognizing the uncertainties due to weather etc., is the central purpose of plant

composition studies. For practical use, the plant analysis technique must not only be able to give such estimates but they must be better estimates (i.e., deviate less from observed increases) than those from any other technique for determining fertilizer requirements.

1. Relation of yield to nutrient supply

Two major considerations are concerned in the relation of yield to nutrient supply: (1) the supply of the nutrient from the soil and (2) utilization of nutrient after absorption by the roots. In the first are all questions of absorption, availability in the soil and effects of acidity, aeration and other factors on nutrient uptake. The second deals with all the questions of physiology of growth, conditioned by two sets of factors: external, such as light, temperature, moisture and supply of all nutrients and internal, mainly nutritive and involving enzymes and growth regulators.

With all external factors except one nutrient maintained at optimum levels, the yield as a function of nutrient supply usually has followed the law of diminishing returns. Mitscherlich's (55) equation described the relationship as an exponential curve approaching a maximum. His exact mathematical form is of no importance except as a method of interpolation and may not fit the data as well as other types of equations. Many investigators have expressed mathematically the relation-

ship between yield or yield response and varying levels of one nutrient.

Little had been done in expressing the yield as a function of two variables (nutrients) until Heady, Pesek and Brown (39) applied the tools of production economics to yield response data. They expressed yield as a curvilinear function of both nutrients (either quadratic or square root functions) plus a linear x linear interaction term. The yield equation as a function of two nutrient variables thus could be diagrammed geometrically as a surface in three planes. From their yield equations as functions of two variables, the most profitable fertilizer application can be determined for any nutrient/nutrient and any fertilizer/crop price ratio. The slope at any point of the surface indicates the marginal product of the fertilizer; the most profitable rate of application occurs where the slope or marginal product equals the fertilizer/crop price ratio. Along any yield isoquant (points of equal yield for varying inputs), the marginal rate of substitution of one nutrient for the other can be calculated and equated to the inverse price ratio of the two nutrients. The yield isocline connects points of equal marginal rates of substitution on the yield isoquants and thus becomes the expansion line for any fixed nutrient/nutrient price ratio. The mathematical model was expanded by Brown _et al_. (10) to include three nutrient variables. This research has been a

highly significant advance in the prediction of profitable yield responses to fertilizer.

Many other factors also affect the relationship between yield and nutrient supply and may be included as variables in the yield response equations. Studies of yield and stand levels by Nelson and Dumenil (56), Dumenil (22) and Duncan (25) showed a curvilinear relationship between the two which may be markedly affected by fertility level. Pesek[1] found that the yield functions involving stand and N levels could be expressed satisfactorily by quadratic functions plus interaction terms.

Little research has been published on the effect of drouth on yield responses to fertilizer but Pesek et al. (61) and Dumenil and Frederick (23) pointed out that responses were quite different under drouth conditions than with normal rainfall. Several factors which were found to influence yield responses to fertilizer under drouth conditions included initial fertility level, time of drouth, subsoil moisture supply, associated insect damage and time and method of fertilizer application.

Few researchers have used multiple regression to investigate the effect of a large number of factors on yield. How-

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[1]Pesek, J. T. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

ever, Ferrari (30, 31) used the principles of multiple regression (graphical multifactor analysis) to determine the influence of 15 factors upon the potato yields in a small district in the Netherlands. These factors included soil fertility, physical and hydrological properties of the soil, crop management and human influence. Yields and measurements of all factors were taken from 230 single-plot sites. He found that 88% of the variance in yields could be explained by 12 significant factors. Peperzak (60) used the same principles of multiple linear regression to study the effect of many soil properties on vegetative yields on highway backslopes. Techniques thus are available to study the relationship between yield and other factors including the nutrient supply.

2. Factors affecting nutrient concentrations in the plant

Many factors affect the nutrient concentration of the plant. Ulrich (84) gave this generalized equation: X = f(S, Cl, T, P, M....) where X, the concentration of a given nutrient, would be the function of soil (S), climate (Cl), time (T), plant (P), management (M) and possibly others. Goodall and Gregory (32) also included pests and diseases.

(a) Soil fertility and other soil factors. In the simplest situation with all nutrients except one maintained at a high level, the concentration of this nutrient in the plant has risen to a certain level with increasing external

supply. As two or more nutrients were varied, the effects on the concentration of these nutrients and other nutrients in the plant have been much more complex, particularly under field conditions. Many conflicting results have been presented in the literature because of different conditions under which the experiments were conducted. Many of the phenomena have not been adequately explained.

Goodall and Gregory (32) generalized that the concentration of the element in the plant depends upon the specific relation of the nutrient to the growth process, rate of uptake and rate of utilization. With N deficiency, growth remains low and no auxiliary meristems are laid down. The uptake of other elements such as P and K does not cease and these are then present in relatively high concentration. (This conflicts with other results, particularly in leaf analysis.) The same is true to a less extent with P deficiency, but with K deficiency, growth does not cease and so the N concentration does not rise to the same degree. They stressed that the relative concentration of the nutrients in the tissues is no measure of the level of supply of any particular element, but depends upon the total supply of all elements.

From his many experiments principally with cereals over almost 20 years, Lundegårdh (49) found that many factors were involved in the nutrient concentration within the plant and that interactions were frequent and complex. He pointed out

that the concentration of nutrients in the medium influenced growth only to the extent to which the nutrients were actually taken up and distributed to the rest of the plant. He concluded that the mutual influence of ions (ion interference or ion antagonism) on uptake by roots and distribution within the plant has been so widespread that a generalization on the proportionality between fertilizer application and nutrient uptake is unjustified. The P content of plants was dependent on the N nutrition as well as the P content of the soil. Accumulation of K was influenced by general rate of growth; with restricted growth caused by N deficiency or drouth, the K content was increased. With N deficiency, concentrations of P and Ca were increased if they were present in greater concentrations than the N. The Ca content should be determined in plant analysis, he believed, because of ion antagonisms between Ca and K and Ca and Mg. Therefore, he emphasized that caution was necessary in the use of leaf analysis because of the many factors which affected the concentrations.

Many other investigators have studied the effect of fertilizers on the concentrations of nutrients in the leaves or other plant parts. Chapman (14), working with 17 soils in pot culture tests, found that N deficiencies caused an accumulation of inorganic P in oats even in P-deficient soils. However, little or no accumulation of inorganic P occurred in early growth stages in plants about equally N and P deficient.

He reported that other earlier workers also obtained similar results.

Shear et al. (72) determined the concentration of N, P, K, Ca, Mg, S, Cl, Na, Mn, Fe, Zn and Bo in tung leaves from many factorial experiments of 2 to 5 elements at 3 to 5 levels in sand cultures. With all other factors constant, plant growth was a function of the two variables of nutrition, intensity and balance, as reflected in the leaf composition of plants at the same stages of development. They emphasized that the functional concentration of all mineral elements in the leaves must be considered and that leaf composition was the only valid criterion of the nutritional status of the plant.

Chapman (13) studied the absorption of nutrients by rubber trees by analyzing the leaves in a series of NPK factorial pot experiments. He found depressed N percentages from P applications, decreased P percentages from K applications and increased P contents in some cases from N applications.

Hill and Cannon (40) determined N, P, K, Ca and Mg in potato petioles from a 3^3 NPK factorial on a muck soil. Multiple linear regression analysis showed a significant, positive correlation between N and P contents at a constant K level, a significant, negative correlation between a combined unit of N and P on K content and highly significant, negative correlations between K and Mg and K and Ca contents.

From a fertilizer experiment in three seasons, Atkinson et al. (3) extracted the major nutrients from potato stems with sodium acetate solution. The amounts of nitrates and K in the plant tissues were usually increased from applications of these elements but concentrations of phosphates were not affected by P fertilization. Frequently, when the nitrate concentration was increased, that of phosphate was decreased.

Van der Paauw et al. (90) checked the relationship between the P contents of grass and soil test values on a large number of plots in the Netherlands. Since they found a positive, linear relationship between N and P contents in the grass, the correlations between P content of the grass and soil test P were considerably improved by adjusting the P percentages to a mean N level. These correlations largely eliminated the effects of different stages of physiological development and of varying botanical composition, they said. The pH and humus content also had some effect on the P content. In another series of experiments on potatoes, van der Paauw (89) found that the correlation between the K content in the tops and K soil tests was much improved by eliminating the effects of N content, clay content and "lime" content by the method of "poly-factor analysis" (graphical multiple covariance).

Samuels and Capo (65) studied the effects of fertilizers on the nutrient concentrations of sorghum in the greenhouse

and of sugar cane and coffee leaves in field experiments. Application of each nutrient increased the concentration of that nutrient in the plant. The N fertilizer had no consistent effect on P content of sorghum or coffee leaves but did lower the P concentration of the sugar cane leaf. It increased the K content of sugar cane and had no effect on Ca contents. The P fertilizer decreased N percentage of sorghum and sugar cane, increased K percentage of sugar cane and decreased the Ca percentage of coffee. The K fertilizer decreased the N and Ca percentages in the leaves of all crops but had no consistent effect on the P percentage. Increasing Ca levels increased P and K percentages of coffee and decreased the N percentage in sorghum. Where decreases in concentrations occurred, these decreases were offset by increases in the weights of the parts sampled. Thus in these experiments, only a dilution effect was present, not ionic interactions or antagonisms.

Tremblay and Baur (79) found that K fertilizer increased the K content in the leaves, petioles and stems of peas but low rates of N and P had no significant effects on K concentration provided adequate K was also applied. Haddock and Linton (34) found that 80 pounds of N per acre had little effect on P percentage of pea vines or on yields in their fertilizer and irrigation experiments.

In an NPK factorial experiment on the unlimed Jordan plots in Pennsylvania with treatments since 1881, Thomas and

Mack (77) found that the P concentration of the third corn leaf was increased markedly by P fertilizer in the absence of K but considerably less in the presence of K. The P fertilizer also decreased the K percentage below the critical level set by Tyner (81); it also increased the Ca percentage and increased Mg without K but decreased Mg with K. The K fertilizer decreased Ca and Mg percentages, particularly in the presence of P fertilizer. Some of the PK interaction effects probably were due to cumulative effects over the years.

Tyner and Webb (83) studied the effects of N, P and K applications on nutrient concentrations in the sixth corn leaf before, during and after silking and found that N and K fertilizers affected the concentrations of each other. The N application, as ammonium sulfate, markedly decreased the K percentage and thus reduced the N efficiency. The highest rate of K, 80 pounds of K_2O per acre, depressed the N percentage slightly. The P fertilizer had no effect on the concentrations of the others nor did the others have any effect on the P percentages. They concluded that the N and K fertilizer balance may be important only on soils low in N or K; the application of heavy rates of the one not deficient might intensify deficiency symptoms of the one already deficient and depress yields. Dumenil and Meldrum have found similar cases from which the data have not been published. However, the

presence of P fertilizer often accentuated the effect of N on K concentration or vice versa.

Chubb and Atkinson (16) sampled the third leaf of corn at tasseling from various fertilizer treatments and found that the P fertilizer had no effect on the P concentration but that the N fertilizer significantly reduced the P percentage. The N and P treatments also reduced the K percentage.

Krantz and Chandler (44), in a study of the effects of N and K rates on the composition of the fifth or sixth corn leaf, found that the P percentage was affected slightly by P application drilled along the row but was markedly increased by level of soil P. The N fertilizer not only consistently increased the N percentages but also increased the P and K percentages of the leaves, particularly on soils high in these nutrients. On one high-P soil, the correlation between N and P percentages in the leaves was very high ($r = 0.94$ to 0.98) for all three sampling dates from about one week before tasseling to the roasting ear stage. The slopes of the three regressions were the same but the intercepts varied, showing that the N/P ratios were different at the different sampling dates. The P and K fertilizers had little effect on the N percentages.

In eight N side-dressing experiments, Bennett _et al_. (4) found that N fertilizer increased the P percentage appreciably in the seventh corn leaf at silking in five of the experiments

and decreased the K percentage slightly in two of them. The N and P percentages were highly correlated. Multiple regression showed that these increases in the P concentration of the leaves were associated with yield responses independent of the N effect.

Viets et al. (91) found high positive correlations (r = 0.84 to 0.89) between leaf N and P in the sixth corn leaf at silking in three experiments under irrigation. The N fertilizer increased the P percentages markedly in two of the experiments. Different sources of N affected the leaf P differently, with ammonium sulfate increasing it the most and calcium nitrate the least. This difference was due to a larger increase in leaf N from the former than from the latter. The P and K applications had little effect on the other nutrients in the leaf.

In four N-stand level-hybrid experiments, Holmes (41) found a significant positive correlation between N and P concentrations in the seventh corn leaf in only one experiment. The N fertilizer increased leaf P in one experiment and there was a positive trend in another. The other two were near the critical level initially. He found a highly significant interaction between hybrids and N levels on the leaf P percentage in both 1953 experiments but none in the 1954 experiments where yields were affected by dry weather. Increased N levels decreased the K percentages of the leaf in both 1953 experi-

ments; significant hybrid x N level interactions on leaf K also occurred in these experiments.

In Kansas experiments affected by drouth in 1952, Ellis et al. (27) found that P and K together significantly decreased the Mg percentage. The N fertilizer decreased the P percentages. In an irrigated experiment in 1954, N fertilizer had no significant effect on leaf P.

In summary, the effect of N fertilizer on P composition, which is of interest in this study, has shown considerable variability. Generally, N fertilizer has increased the leaf P when N availability was low and P availability was medium to high. Several investigators have found a significant positive correlation between the N and P contents in the leaves of various plants. The reason for the increase in P percentage from N fertilization has not been explained fully. Bennett et al. (4) pointed out that the more extensive root system from N fertilization of a low-N soil may increase P uptake. Since N and P are closely associated in the proteins and enzymes, the increased N uptake and utilization in organic materials may increase the utilization of P and increase the uptake gradient for P. Viets et al. (91) found that the increase in P percentage with increased N uptake represented a faster accumulation of total P than of dry weight. They also mentioned that it is possibly due in part to a better developed root system in contact with a greater volume of soil.

Rotations with legumes influence nutrient availability in soils and thus the nutrient concentration in the plant. Andharia et al. (2) and Tyner et al. (82) found that different rotations affected the N concentrations of corn leaves. They concluded that the primary effect of legumes on yields was due to increased N availability for the corn crop as reflected in increased leaf N content. Tyner et al. (82) also pointed out that rotation effects on leaf N varied with the season because of differences in N release due to climatic effects during the growing season. The legume growth in the preceding year also affected N concentrations in corn leaves.

Hanway and Meldrum[1] have found that the position of the corn crop in the rotation may influence the K concentration in the leaves, particularly on low-K soils. Following removal of large amounts of K by meadow crops, the leaves of first-year corn were low in K but leaves of second-year corn had higher K levels because large amounts of K in the stalks were returned to the soil by the first-year corn crop.

Other soil factors such as pH, aeration and physical properties may influence nutrient concentration in the plant or parts of it as numerous investigations have shown.

(b) Climatic factors. Lucas et al. (48) and Weeks and Fergus (92) found that seasonal and weather conditions influ-

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[1]Hanway, J. J. and Meldrum, H. R. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

enced the nutrient concentration of mature plants with the straw or stover varying much more than the grain.

Goodall and Gregory (32) generalized that the internal concentration of nutrients will rise when plant development is slowed by a low level of external factors such as water supply or temperature.

Lundegårdh (49) concluded from many experiments with small grains that the index or content values, S (Spiegelwerten), were partly dependent on rainfall. Under dry conditions, the S_K values rose somewhat above normal but the S_P values were less variable. The S_N values rose appreciably under dry conditions even in N-deficient fields. The variations in S_P and S_K were not sufficient to disturb the diagnosis by plant analysis unless drouth was severe but rainfall conditions had to be considered when interpreting S_N values. Under wet conditions, he found that all S values decreased somewhat.

Scarseth (68) quoted data of Ohlrogge in which drouth affected the P availability from different methods of application. Plant tissue tests indicated low P in the corn where 120 pounds of P_2O_5 was drilled along the row but high P where the same rate was plowed under. Very few active roots were found in the dry soil near the surface where the row fertilizer was placed but abundant root growth was found in the moist soil at plow depth where much of the plowed-under P was lo-

cated. As drouth progresses, the decreased root activity from the surface downward causes decreased nutrient uptake from an area that is usually highest in N and often highest in P supplies, he concluded.

From four years of experiments on irrigated, calcareous soils of Utah, Haddock (33) related the soluble P content of sugar beet petioles to soil moisture conditions and fertilizer placement. Using P^{32} to study P uptake, he found higher amounts of P in the petioles from the treatments with higher moisture levels. Differences were slight at the higher moisture levels between band placement 6 inches deep and 4 inches to the side of the beets and broadcast and mixed into the surface 2 inches. When the soil was kept dry, the P content of the petioles was lower but more accumulated in the plants from the deep-placed P than from the surface broadcast placement. The soil moisture levels influenced utilization of fertilizer P; with deep placement, 40 and 24% of the P uptake came from the fertilizer at low and high moisture levels, respectively. He thought that the increased P uptake at moist soil conditions was because the cooler soil, due to a high evaporation rate, held more CO_2 which then brought more soil P into solution. Since these soils had 2 to 3 times more CO_2-extractable P in the surface 6 inches than in the next 6-inch layer, the increased P uptake may have been due to increased root activity in the surface 6 inches under moist conditions.

Haddock and Linton (34) also found that increased moisture levels increased the acetic acid-soluble P in pea vines.

Spies (75) calculated critical levels of 2.33 and 2.49% N in two experiments under dry conditions. These agreed with the critical level of 2.5% N found by Nicholson and Pesek[1], also under drouth conditions. Spies concluded that critical N levels may be lower in dry years than in normal-moisture seasons.

Under severe drouth conditions, Ellis et al. (27) found limited increases in N and P content of corn leaves from N and P fertilizers although leaf levels were low. Yields which averaged about 30 bushels were not affected by these fertilizers. On the K-deficient soils, the K fertilizer increased the leaf K markedly and yields somewhat. The critical K level appeared to be similar to Tyner's (81) critical value. In irrigated corn, they found leaf levels of 2.5 to 2.7% N at tasseling in corn whose yields were restricted to 50 to 60 bushels by drouth.

Chapman (13) found that leaves from rubber plants suffering from water-logging or drouth were often low in nutrients despite heavy fertilization. Leaf composition then was not correlated with growth.

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[1]Nicholson, R. P. and Pesek, J. T. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

In Hawaii, Clements (18) found that the N index of sugar cane was characteristic of the prevailing temperature and elevation of the field. The normal N level was higher in the cooler areas. Using multiple regression to study factors affecting the P index (per cent P) in the sheath tissue of sugar cane, Clements (17) found that two dominant factors, other than P availability, were sheath moisture and total sugars. From the multiple regression analysis, he calculated a Standard P Index (SPI) as a function of the actual P index, sheath moisture level and total sugar level. In effect, the SPI converted the P index to normal growth conditions by compensating for high moisture, varieties having high tissue moistures and drouths affecting the P levels.

(c) Time of sampling. All investigators have found that the concentration of nutrients varies in different plant parts throughout the growing season. Because of this, investigators of leaf analysis have standardized their testing on a part of the plant taken at a definite time or stage of maturity. This is necessary to reproduce results in prediction and diagnostic purposes. A practical problem in the use of leaf analysis is how critical is this time of sampling.

Lundegårdh (49) found that the index values of flowers and fruits varied to a small extent even with large variations in nutrient supply but the values in the leaves and stems varied much more. Towards the end of the vegetative period,

the N, P and K values decreased in the leaves of all cereals but the Ca index remained nearly constant. However, over a period of about two weeks before flowering and during pollination, all index values either remained almost constant (particularly for K) or fell not more than 20 to 25%. For practical purposes, the period between full emergence of the heads and pollination is easy to recognize and should be most suitable for leaf analysis, he concluded. The nutrient concentration in the stem also reflected the nutrient status but in cereal plants the periodic variations of K and Ca was much more pronounced than in the leaves.

Salter and Ames (64) found that the N and K percentages of whole corn plants decreased from latter June until maturity. The P percentage decreased until July 26, then increased until August 23 and decreased thereafter. The period between July 26 and August 9 samplings (tasseling and silking) showed little change.

Thomas and Mack (77) sampled the third corn leaf four times (July 6 to August 25). The N percentage decreased from July 6 to August 8 with little change between the last two samplings; the rate of decrease was less on the N treatments than those without N. The K percentage decreased on most of the treatments between the July 21 and August 8 samplings with little difference between the first two and last two samplings. There was little change in K levels on the P and NP treatments

which had very low levels initially. There was no difference in the P content between the first and third samplings except decreases on the check and K treatments. The P content was highest on all treatments at the last sampling.

From the sixth corn leaf sampled at four times (July 16, 30, August 16, 30) Tyner and Webb (83) found that the N and P percentages decreased almost linearly with time. The K levels were about the same at the first and last samplings but were at the maximum and the same at the second and third samplings. Fertilizer treatment had little effect on the rate of change of any of the nutrients in the leaf.

Sayre (66) found that the concentration of N and K in corn leaves gradually decreased during the season but that of P increased to a maximum at tasseling and then slowly decreased. The concentration of all nutrients in the leaves declined very slightly from tasseling until two weeks after silking. However, nutrient levels were high in this experiment.

Samuels and Capo (65) found that increased concentrations of nutrients due to fertilization tend to disappear with increasing age of plants. In sugar cane leaves, the difference in concentrations from treatment was significant at 3 months of age but disappeared at harvest (10 months) despite yield differences.

Sampling the fifth or sixth leaf at three times (about one week before tasseling, at full tassel and at roasting ear stage), Krantz and Chandler (44) found that the N and K concentrations decreased during the sampling period. The P content was highest at full tassel in two experiments and lowest at full tassel in another.

Hanway and Pesek[1] found that changes in nutrient concentration in the seventh corn leaf with time were not consistent for all nutrients or treatments, as previous references also have shown. The P content increased from the first sampling when tassels were first emerging up to the last sampling three weeks later in two 1951 experiments. The K percentage decreased in the one with a high K level but did not change in the other one which had a lower K level. In a PK factorial in 1954, the P and K percentages decreased regularly from the time of first tassels to 10 days after silking. In another experiment in 1954, the P content increased from first tassel emergence to full tassel but decreased in the next two samplings; the K content decreased with time. In a 1955 experiment, the N percentage decreased with time, the P percentage remained constant except for some decrease at the last sampling and the K percentage increased from first tassel to full tassel and remained constant thereafter.

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[1]Hanway, J. J. and Pesek, J. T. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

All of the studies have shown that the N percentage in corn leaves decreased with time during the period around tasseling and silking but the rate of decrease varied somewhat with the N availability of the soil. The K percentage usually decreased with time through this period but there were several exceptions. The P percentage with time followed no definite pattern and apparently would be difficult to predict. Since the N and P contents have been shown to be closely correlated, the P content might be expected to decrease as the N does. The different patterns may reflect differences in P availability of the soil and slower translocation of P than N from the leaves to the developing ear.

(d) Plants and varieties. Critical levels of nutrient concentration vary among plants as shown by Goodall and Gregory (32). However, groups of similar plants may have about the same critical values.

Of much more practical importance, and which has received little attention, is the influence of variety on plant analysis. Several workers have pointed out varietal differences in nutrient concentration of plants at the same fertility level. Others have found only small or inconsistent differences. If varieties differ not only in composition but also in potential response to fertilizer at the same composition, a separate concentration-yield relationship then may have to be determined for each variety or group of varieties. Of

course, varietal differences in responses to fertilizer will affect the accuracy of any other method used to predict responses. Goodall and Gregory (32) pointed out that varietal differences in composition represented differing ability to absorb nutrients in many cases and not differing reaction to a given internal concentration.

Holmes (41) reviewed much of the limited research on varietal differences in composition and yield responses. He studied the composition of the seventh leaf and yields at various N and stand levels of 15 single-cross hybrids (all combinations of six inbreds). Highly significant differences in yield and leaf N, P and K occurred among hybrids; these differences appeared to be due to differences among inbreds. His data suggested a hybrid x season interaction on nutrient uptake and utilization. The relative composition of the hybrids varied from the first to the second year; many were below average one year and above the next or vice versa. Significant hybrid x N interactions on leaf N, P and K were found.

Sayre (67) found wide variations of N, P and K contents of the ear leaf of 13 inbreds sampled shortly after silking. The ranges were 1.82 to 2.46% N, 0.162 to 0.336% P and 0.97 to 2.57% K.

Since most commercial corn varieties are double-crosses involving four different inbreds, the composition is likely to deviate less from the mean than that of inbreds or single-

crosses. If further research shows that varietal differences are important in the use of plant analysis, the problem will be further complicated because closed-pedigree hybrids are used on most of the corn acreage.

(e) Soil and crop management. These factors are many but the ones discussed will relate to method and source of fertilizer application, tillage methods, stand levels, weed control, insects and diseases.

Of interest in this study is the effect of the method of P application on leaf P content. Scarseth (68) reported one case under drouth conditions where plant tissue analysis showed a much higher amount of P in the corn plants from broadcast and plowed-under application than from the same rate applied in the row.

There was a spurt of interest in studying P uptake and growth responses from various methods of application when radioactive P became available. Unfortunately, only a few experiments were conducted with corn and these experiments were not continued long enough to compare the effects of various methods over different soils and seasons, particularly comparisons of broadcast and row placement.

In the first series of experiments using radioactive P, Nelson et al. (57) found that, of four crops studied, corn represented one extreme in P absorption. A high proportion of P absorbed early in the growing period by corn came from the

fertilizer in a double band 2½ inches from the seed, but at the end of the season, corn was absorbing less P from the fertilizer than any other crop. There was a marked early growth response from the P fertilizer, but by silking, the plants in the plots without added P had the same size as the P treatments. There were no significant yield differences. They reported the same type of growth and yield responses had occurred in earlier field experiments. They found that corn developed a very extensive root system and absorbed a relatively large amount of P in later growth stages. Sayre (66) also reported a similar P uptake pattern by corn. Krantz et al. (45) repeated similar experiments the next year with radioactive P and found that the P uptake behaved the same way when P fertilizer was banded along the row.

Nelson et al. (58) studied several placements of phosphate including 4 inches deep and 3 inches to each side of row, mixed 4 inches deep and 6 inches wide under the row and broadcast and disked in. They found little difference in P uptake between the first two methods but the broadcast fertilizer was less efficient throughout the season. A broadcast and plowed-under treatment also would have been of interest. No significant yield differences were found since drouth limited yields to 65 to 70 bushels. They concluded it is possible to get early growth stimulation by one placement and to

increase further the P uptake in later growth stages by another placement.

One point that was understood, apparently, but not stressed was the rate of P uptake as a function of time. This was illustrated in a method study on soybeans by Welch et al. (93) where banded P, 3 inches to each side and 2 inches below the seed, was compared with broadcast and disked-in P. They stated that band placement resulted in a much larger absorption of fertilizer P than broadcasting at the first five sampling periods. This statement, however, was somewhat misleading. If the P uptake from the fertilizer is plotted against time for both methods, the rate of uptake is much higher from the band placement than from broadcast up to the third sampling (about one month after emergence). Between the third and fifth samplings, the rates of uptake from the two methods were about equal. After the fifth sampling, the rate of uptake from the broadcast method was higher. The P percentage in the whole plant was higher from the band than from broadcast placement at the first four samplings, the same at the fifth sampling and higher from the broadcast than band at the sixth sampling.

Stanford and Nelson (76) found that the P uptake pattern varied at three locations where placements were compared using radioactive P. In a Clarion soil where germination was retarded by drouth and yields were low, the rate of P uptake was

higher from seed level (2 inches) than from deep (5 inches) placement up to the third sampling (about July 8). After that, the uptake rates were equal. On the Webster soil of pH 7.1 where late planting, early dry weather and N deficiency before tasseling limited yields, the rate of uptake was the same from both methods during the season. On another Webster soil, pH 6.7, where moisture conditions were favorable early but drouth in July and August limited ear development, the rate of P uptake was higher from the 2-inch depth up to the third sampling (July 16, 3 feet high) but after that was higher from the 5-inch depth of placement.

In order to study the influence of root activity on the P uptake from different methods of application, Hall et al. (35) placed radioactive P at various depths and distances from the plant and determined the P uptake by the plant with time. At the end of four weeks after planting, the root system of corn developed in a hemispherical volume extending over 18 inches deep and 24 inches in radius. Prior to maturity, the roots extended laterally beyond 30 inches. The P^{32} placed 3 inches deep contributed half of the plants' supply of P^{32} through the first seven weeks and over one-third throughout the growing period. The P^{32} at 8 inches, 13 inches and 18 inches contributed about 1/3, 2/9 and 1/9 of the plants' supply, respectively. The root activities at the various depths were similar on a sandy loam and on a clay loam which had a compact layer in

the subsoil. Some implications of this study were: (1) corn draws water and minerals from a large volume of soil, (2) a fertile soil of considerable depth is needed for maximum production, (3) ordinary methods of hill or row placement for corn are relatively insignificant except for early growth and (4) cultivation should be early and shallow as practical to reduce root injury.

Larson (46) studied different methods of P application for sugar beets under irrigation. In one experiment, fall plowed-under and spring deeply disked-in P gave greater yields, early growth and P concentrations in the foliage than did banding at either 2- or 5-inch depths and 2 inches from the seed. In another experiment, fall plowed-under P gave greater yields, early growth and P concentrations than broadcast and disked-in or banded P 3 inches deep. An indirect method of measuring the relative effectiveness of P placements using radioactive P also showed the superiority of the plowed-under placement. He also found that 14, 47 and 39% of plowed-under fertilizer was located in the 0-2, 2-5 and 5-7 inch layers, respectively. In addition, a banding effect was present between the plow slices.

In 11 experiments from 1952 to 1954 with hill-applied P sources of different water solubilities, Webb[1] found little

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[1]Webb, J. R. Unpublished data, Iowa Agr. Exp. Sta. Private communication. 1957.

difference in the P percentages of the seventh leaf taken at silking time due to rates of P and no difference among sources. The P percentages averaged 0.221, 0.227 and 0.231 for 0, 15 and 30 pounds of P_2O_5, respectively. The yield responses from superphosphate were about 8 and 12 bushels from the two rates with about half as much response from the source with the lowest water solubility. In a similar experiment in 1955 with large yield responses, he found significant differences among rates and sources in the P contents.

In four plowed-under experiments comparing sources of P fertilizer, Webb[1] found significant differences in P content of the seventh leaf taken at silking time due to rates but none among sources. The P percentages and yields averaged 0.236, 0.259 and 0.269% P and 69, 82 and 86 bushels from 0, 30 and 60 pounds P_2O_5, respectively. Comparisons between calcium metaphosphate and superphosphate in another series of experiments also showed no difference in the leaf P contents.

In the most relevant experiments pertaining to broadcast and hill-placed P applications, Webb[1] found that 20 pounds of P_2O_5 broadcast increased the P content of the seventh leaf taken at silking time considerably more than the same rate applied near the hill although yield increases averaged the same over all experiments. In four experiments in 1954, the

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[1]Webb, J. R. Unpublished data, Iowa Agr. Exp. Sta. Private communication. 1957.

P percentages were 0.235, 0.239 and 0.258 from 0, 20 pounds P_2O_5 near the hill and 20 pounds P_2O_5 broadcast and plowed-under, respectively. In five experiments in 1955 where the P fertilizer was broadcast and disked-in on three of them, the P percentages averaged 0.231, 0.246 and 0.259 from none, hill and broadcast P, respectively.

Corn leaf samples taken at silking time often do not show the P applied in a hill or row fertilizer applied at planting time (split-boot attachment) although the method increases yields. The leaf samples probably reflect the P-supplying power of the soil or availability of the fertilizer during the preceding several weeks. During this period, the growth rate and P needs of the corn crop increase. The research mentioned previously shows that the rate of P uptake from row- or hill-placed P fertilizer at shallow depths is rapid during early growth when total P uptake is low, but it slows down towards the beginning of the "grand period of growth" when the rate of P uptake increases and root activity near the surface decreases. Moisture conditions during this rapid growth period also will influence the root activity near the soil surface. The rate of P uptake from broadcast P fertilizer, particularly plowed-under, is slow in early growth stages but increases as the root activity expands deeper and over a wider area during the period when corn makes its rapid growth from 5 to 6 weeks after emergence until tasseling.

The failure of hill or row fertilizer to have much effect on the leaf P content may also be due, in part, to a dilution effect. In this way, the P uptake from this fertilizer is diluted with relatively more dry weight thus decreasing its concentration. Dumenil and Hanway, in leaf composition studies from which the data have not been published, and Webb[1] have found that this dilution effect may occur to a varying degree in corn leaves. In many cases, however, differences between the dry weights of the leaves at silking of the hill-applied and broadcast fertilizer treatments were small although the dry weights of both were higher than the unfertilized treatment. The dilution effect does not appear to be the primary cause of the smaller effect of hill or row than broadcast P fertilizer on the leaf P content.

Tillage methods also may influence the nutrient concentration in corn. Bower et al. (9), Lawton and Browning (47) and Parker et al. (59) found that various tillage methods such as listing, subsurface tillage and mulch tillage often reduced the N and K contents and subsequent yields when compared with conventional plowing.

Stand levels often have marked effects on yields and yield responses to fertilizer. Tyner (81) mentioned that increased stand levels decreased the N content of corn leaves

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[1]Webb, J. R. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1958.

and often from above to below the critical level. In eight stand level-fertilizer experiments, the results of which have not been published, Dumenil and Hanway found that increased stands decreased both the N and P contents of the corn leaves but either had no effect on or slightly increased the K content. Several experiments showed stand level-fertilizer interactions on nutrient contents. At the higher fertility levels, N and P contents were reduced less by increased stand levels than at the lower fertility levels.

In a study on the effects of stand levels, N levels and different hybrids, Holmes (41) found results similar to those in earlier experiments. The results were not as consistent probably because moisture was limiting to a varying degree at all locations. In two of the experiments, significant, positive N x stand interactions on leaf N and P were present. Increased stand lowered both the leaf N and P contents markedly at the zero N level but very little at the 200 pound rate of N level. In one experiment, a significant hybrid x stand interaction on leaf N and P occurred. Increased stand levels significantly decreased N content at all four sites and P content at two sites.

There is little information in the literature on the effect of weeds, insects or diseases on plant composition. It is reasonable to expect that competition for nutrients and water by weeds, damage to the conducting tissues by corn bor-

ers, damage to the root system by corn rootworms and damage to the plants by diseases such as root rots and leaf blights would decrease nutrient uptake and composition of the plant. There is ample evidence that yield responses from fertilizers may be quite different from normal in the presence of severe damage from any of these sources.

3. Relation of yields and yield responses to nutrient concentrations in the plant

(a) Yields. As the level of a deficient nutrient is increased, it has been shown that both yield and nutrient concentration increase, at least in certain plant parts and at certain stages of development. Attempts have been made to express this relationship of yield to concentration in a mathematical form. Pfeiffer *et al*. (62) proposed a hyperbolic formula. Mitchell (53) found the relation to be nearly linear until the maximum yield was reached.

Macy (52) divided the curve relating yield and nutrient concentration into three linear segments: (1) the "minimum percentage" where yield rises but internal concentration remains constant at its minimum amount, (2) the "poverty adjustment" region in which both yield and concentration rise linearly and (3) a "luxury consumption" region in which yield remains constant but concentration still rises. The transition from the "poverty adjustment" to "luxury consumption" region

takes place at the "critical percentage". It is unlikely that yield and concentration of one nutrient are related over the entire range if conditions cover a wide range of combinations of other nutrients. Another difficulty in his concept is that he tries to define what is probably a continuous function as a series of linear segments. There is also little evidence in the literature of the presence of the "minimum percentage" segment.

Several others have expressed the yield as a function of the concentration of a single nutrient either graphically or mathematically. Tyner (81) correlated corn yields with the concentration of a limiting nutrient in the sixth corn leaf at adequate quantities of the others. He found highly significant individual correlations and regressions of yield on percentages of N, P and K. For each, he calculated a linear regression equation. The N relationships appeared to be curvilinear but no deviations from linearity were apparent in the P and K regressions. He calculated critical percentages of 2.90% N, 0.295% P and 1.30% K on an air-dry basis (3.1% N, 0.315% P and 1.4% K on an oven-dry basis). He did not explain how he calculated the critical N level but did state that the critical P and K levels were obtained from the yield level associated with the critical N level. This yield then was introduced into the regression equations of yield on P and K percentages to get their critical levels.

Lynd et al. (50) found correlation coefficients of 0.54 in 1947 and 0.72 in 1948 between yields and N contents in the corn leaves from a rotation-fertility experiment. There was little correlation between yields and P or K percentages.

Viets et al. (91) found high correlations between yields and N percentages in the sixth corn leaves in three irrigated experiments. The linear regression coefficients of the experiments were nearly the same but the intercepts of the equations were markedly different. Therefore they concluded that the regression of yield on leaf N could not predict yields accurately. They did not analyze the combined data to determine how much of the variance of yields could be accounted for by the regression of yield on N percentage.

Andharia et al. (2) found a high correlation (r = .97) between leaf N and mean corn yields in a rotation experiment. Spies (75) separately correlated yields with leaf N, P and K percentages in three NPK factorial experiments. He found highly significant correlations between yields and N and P percentages but no relationship between yield and K percentage. Holmes (41) also found significant correlations between yield and leaf N in 3 of the 4 experiments, although the correlation coefficients were not large.

Goodall and Gregory (32) emphasized the value of employing multiple regression analysis where data on simultaneous variation in more than one nutrient are available. Tyner (81)

pointed out that his regression equations assumed no limiting factors except the nutrient and made no allowance for interactions between various elements. He recommended the use of experiments designed to study the joint functional regressions accompanying simultaneous variations in N, P and K percentages in order to develop more accurate yield equations.

Few references are available dealing with the expression of yield as a function of two or more nutrients, particularly where rates and combinations of two or more nutrients were applied. Chapman (13) studied the relations existing among N, P and K content of rubber leaves and growth rate of seedling rubber or latex yield of mature rubber. Although no mathematical relationships were given, he implied that they had been determined. Latex yield was correlated particularly with leaf N and under some conditions, both were depressed by P fertilizer. The composition and growth rate were usually linearly related.

Emmert (28) related yield to the acetic acid-soluble N and P in tomato petioles by multiple regression analyses although the partial regressions and correlations were of most interest. Since the relationships were often curvilinear, he divided the data into groups for linear regression analysis. The correlations between yield and N or P contents were often significant in lower segments but not in the upper ones; evidently contents had risen above the critical levels. The N

content-yield relationship was closer at the higher P levels. He found that the optimum N levels for maximum tomato yields varied during the different growth stages.

From a 3^3 NPK factorial in three consecutive years, Hill and Cannon (40) used multiple linear regression to study the relationships among the nutrients extracted from potato petioles and yields. Since some of the relationships were curvilinear, these data were divided into groups or sub-ranges by visual inspection of scatter diagrams. A linear multiple regression was then run on each of the sub-ranges. They found that the $r_{YK.NP}$ (correlation between yield and K independent of N and P) was positive and highly significant at levels less than 3000 ppm. (parts per million) K. At levels more than 3000 or 4000 ppm. K, the correlation was negative or zero. The $r_{YP.NK}$ was zero at less than 70 ppm. P but negative and significant at greater than 70 ppm. P in two years of three. In the third year there was a significant PK interaction on yield shown by the $r_{YP.NK}$ which was negative and highly significant at K levels of 250 to 3000 ppm. but about zero above 4000 ppm. K. The $r_{YN.PK}$ varied with season. In one year it was zero at 15 to 200 ppm. N but negative and highly significant at greater values of N. It was positive and significant at 30 to 200 ppm. N but negative and highly significant at 200 to 1000 ppm. in another year. It was negative, linear and significant in the third year. This study clearly illustrated

some of the complexities involved and also the potential value of multiple curvilinear regression methods in yield-plant analysis relationships.

Van der Paauw (88) and van der Paauw et al. (90), using plant analysis in a different way, used the P and N contents of fertilized grass plots to study the relationships between percentage yields and P soil test methods. Plotting the P soil test against the P content of the grass, they found a curvilinear relationship. By "graphical poly-factor analysis" (graphical covariance), the P contents were adjusted to a mean N level, thus giving a closer fit between the P soil test and P content of the grass. There was a positive linear relationship between the deviations of the P contents from the original curve and their N contents. Although, they considered the correlations between P soil tests and corrected P contents of the grass as a more sensitive measure of the availability of the P in the soil than the correlations between P soil tests and relative yields, there was little mention of considering relative yields as a function of the N and P percentages in the grass.

Van der Paauw (89) used the same technique to determine the reliability of the K soil test for potatoes. The relationship between the K percentage in the tops and K soil test was much improved after the effects of clay content, "lime" content and N percentage were eliminated.

From eight N rate experiments on corn, Bennett et al. (4) determined the regression equations of yield as a function of leaf N and P for each experiment and for the pooled data. The N fertilizer increased the P percentage of the corn leaves in most of the experiments. The multiple regression analysis showed a relationship between yield and P content of the leaves, independent of any effects due to N content. For the pooled data $r_{YN} = 0.80$, $r_{YP} = 0.78$ and $R = 0.85$. The high correlation between the N and P contents explained why the multiple correlation of the yield on both was only somewhat better than the simple correlations of yield on either one. The critical N levels were found to be approximately 2.8 to 3.0% N.

Viets et al. (91) also used multiple regression in relating yields to N and P contents of corn leaves. In all three experiments, yields were highly correlated with N and P percentages, both of which were highly correlated ($r = 0.84$ to 0.89). In one experiment, both N and P in the leaves had independent effects on the yields, as shown by the significance of both partial correlation coefficients. Because of the high correlation of N and P percentages, the multiple correlation coefficients were only slightly larger than the simple correlations of yield on N percentage. In all experiments, yield was linearly related to leaf N with little evidence of a statistically significant departure from linearity

that could be called the critical N level. However, it was possible to calculate the critical N level in one experiment from the yield curve; this level was 2.83% N. They also concluded that leaf P data for assessing P status of the plant are worthless unless the N status of the leaves is also known.

In three 3^3 NPK factorials on corn, Spies (75) used multiple regression to relate yields to leaf N, P and K (R = 0.57 to 0.85 for the three locations). From the pooled data, after omitting the K per cent from the regression equation since none of its standard partial regression coefficients with yield was significant, the equation for pooled yields was calculated as a function of the leaf N and P (R = 0.81). From the maximum yields calculated with the Spillman equation and the regression of yield on N percentage, the critical N levels in two of the experiments were found to be 2.33 and 2.49% N. These were lower than most reported, probably due to dry weather.

(b) Yield responses. Although the prediction of yield from leaf analysis may be of practical interest, Goodall and Gregory (32) stated that the use of plant analysis to diagnose fertilizer requirements is not directed to forecasting the yield but rather to forecasting the response from nutrient application. The minimum requirements to develop this method would be data from plants at various levels of one factor with others adequate. The data would include the percentage of the

varying nutrient in definite organs at a definite stage and yield increases from the various levels of the nutrient. Yield increases from any specified level could then be graphed as a function of the initial nutrient concentration.

The data in several of the foregoing references relating yield to nutrient concentration could be shown in this fashion. Although Bennett et al. (4), Viets et al. (91) and Spies (75) showed a highly significant relationship between increase in yield and increase in N percentage from N rates, they did not show the relationship of yield increase from any given rate to the initial N percentage.

Other data of this kind, using a single variable, have been reported by Crowther (21) on cotton, Emmert (28) on tomatoes and Lundegårdh (49) on oats, other small grains and sugar beets. Lundegårdh (49) showed that the relationship between yield increase and concentration of a single nutrient is a concave hyperbolic curve, $y = a/x^c$ where y is the yield increase from a specified amount of fertilizer, x is the concentration of the nutrient in the plant and a and c are constants.

It is important to consider the effect of levels of other factors in the yield increase-nutrient concentration relationship. Pfeiffer et al. (62) claimed that this relation expressed in terms of percentage increment in yield is independent of the supply of other nutrients and of environ-

mental factors. However, relative yield increments are of no practical use in predictions of response to fertilizer since the absolute increase is not implied. Macy (52) also claimed his critical percentages were largely independent of the levels of other growth factors. These claims, based in part on the constancy of Mitscherlich's effect factor "c", have been disproven in recent years (6, 32, 49).

Lundegårdh (49) showed that the absolute increase in yield, resulting from a given fertilizer application to plants with a particular internal concentration of the nutrient applied, was markedly affected by the level of other nutrients. From his data, he formulated the relationship between index values and yield increases as a simple hyperbolic formula: $y = \frac{b}{x^c} K_i - a$ where x is the index value, y is the yield increase from a standard quantity of nutrient, a, b and c are constants and K_i is the "interference factor" which represents the effect of a second index value. Only three K_i values were used to cover the range of values of the second nutrient, although its effect was probably a continuous function. He did not show how well his equation fitted the data since no correlations or scatter diagrams were shown, although group averages over wide ranges were shown. No attempt was made to show the relationship among the concentrations of all three nutrients and yield increases.

Van der Paauw (88, 89) also presented data which could be used to show the effect of another nutrient or soil factor on the relationship between yield increases and nutrient content. He made no direct comparisons, however, since he used percentage of maximum yield in his studies.

Goodall and Gregory (32) mentioned that the effect of other factors on yield increases could be determined by analyzing the plants for all nutrients. The responses could then be represented in terms of combinations of concentrations, which could be shown as a solid diagram for two factors. For more than two factors, the relationship could be represented by a regression equation. They pointed out that at the time their review was written (1945) no data of that kind were available but Lundegårdh's research indicated the right direction. No data using yield increases and composition have been analyzed this way since then although yield has been expressed in a multiple regression equation as a function of two or more nutrients in the plant, as reviewed earlier.

D. Selection of a Technique

In selection of a technique for plant analysis, Goodall and Gregory (32) stressed that many problems were involved such as when and what to sample and how to analyze and interpret. Some have tried to select the technique with a priori considerations; others have assumed that techniques giving the

largest differences due to fertilizer treatments were best; others have correlated plant composition with soil tests or total nutrient uptake with fertilizer needs. In testing the sensitivity of methods, the differences must also be compared with their standard errors or coefficients of variation. They pointed out that the correct criterion for assessing the value of any method of using plant analysis for fertilizer requirements is agreement between forecast and actual yield responses. Techniques of correlation and regression, either linear or curvilinear, between yield response and nutrient content can be used. Where data on simultaneous variation in two or more nutrients are available, the values may be analyzed by multiple regression.

The stage of growth at which plant samples are taken is complicated by seasonal variations in soil nutrient supply and plant composition. In most cases, samples have been taken at some definite, recognizable stage of physiological development. Many different parts have been sampled. Ulrich (87) specified that the plant part must be easy to sample, have a relatively constant critical level, high sensitivity (wide range of values), furnish an ample amount of plant material for analysis and be suitable for analysis of several nutrients. Goodall and Gregory (32) concluded that the sensitivity usually is greater in the leaves than in other organs.

For small grains and grasses, Lundegårdh (49) found that the index values of leaves were relatively constant during a two-week period before flowering and during pollination. The leaf samples he took consisted of all leaves from plants cut about 4 to 6 inches above the ground.

In a sampling study with canning peas, Tremblay and Baur (79) found that either leaf blades or petioles at the third node from the top of the plant at the 8- or 9- node stage best indicated the K status of the soil. The leaves in the upper part of the pea plants were much more sensitive to different rates of K fertilizer than the lower leaves. The K content increased from the bottom leaves to the top leaves, from 0.5 to 1.8% on the check plots and from 0.8 to 3.6% on the high-potash treatment. In another study, they (80) found that either the tops or leaves at the third node from the top at the 4- to 8- node stage best indicated the P status. Haddock and Linton (34) concluded that early sampling, immediately preceding blossoming, was more sensitive than a later sampling since it showed a significant correlation between P content of the vines and yield and the later sampling did not. Ulrich (86) found that ladino clover petioles analyzed at various times reflected the P and K status better than the leaf blades.

The most extensive sampling for determining the sensitivity of different plant parts was made by Clements (18). From

24 crops of sugar cane and starting when the cane was 2 to 3 months old, cane shoots were sampled every 35 days until harvest, nearly two years later. The shoots were subdivided into many parts and analyzed. From over 100,000 chemical analyses, the most sensitive index tissues for N, P and K and other measurements were selected using correlation methods of relating the contents of the various plant parts. The nutrient contents in the plant parts were not correlated with yields initially. Next, he determined the critical nutrient indices, at first using field behavior and associated yields and finally by using curvilinear regression methods to correlate yields and corresponding nutrient indices in experiments. Clements' method of tracing the composition and physiology of sugar cane through its growing season for diagnostic purposes is called "crop logging".

Recently, Burr (11) has questioned the use of Clements' leaf and sheath index tissues and indicated that stalk analysis may give a better diagnosis of sugar cane nutrition. However, little data on the relationship of the plant analysis data to yield or yield increases were given.

Few detailed sampling studies have been made on corn to determine the sensitivity at various growth stages or of various plant parts. Thomas and Mack (77) sampled the third leaf from the base of the stalk at four different times but no correlations with yield were made. Ellis et al. (27) sampled the

third leaf at tasseling time one year and at four times during the season in another year. Relationships were poor because of drouth. In a different manner, Lynd et al. (51) sampled the third functioning basal leaf which was the 4th, 5th or 6th leaf in some cases. These "morphologically homologous" leaves thus were selected because of severe necrosis of the lowest leaves caused by nutrient deficiencies. The midrib was also removed and only the blade material used for analysis. Such sampling has two disadvantages, time consuming and decreased sensitivity since differences among fertilizer treatments would be decreased. The corn also was sampled every week between July 20 and August 7 but only one replication of the NPK factorial was sampled each week. No conclusions could be made because of extreme variability. In cases of severe nutrient deficiencies, the third leaf would be undesirable since many dead leaves would be included in the sample.

Tyner and Webb (83) sampled the sixth leaf at different times during the season. The sixth leaf (only the blade portion was selected for sampling since the position is easily recognized if the lower leaves prematurely drop. It is the leaf immediately below the leaf in whose axil the uppermost ear is borne; it is also the blade at the second node below this ear. In a further discussion, Tyner (81) listed the following reasons why the sixth leaf at silking time was selected in his study of critical N, P and K levels: (1) the stage is

easily recognized and described, (2) since all varieties mature in about the same number of days after silking, the physiological stage of maturity is thus the same for all varieties, (3) the weight of vegetative parts is at or near the maximum at this time and (4) this is a period when nutrient demands of the plant are very high.

Krantz and Chandler (44) sampled the fifth or sixth leaf from the base, the leaf just below the lower ear, at three times. Iowa workers (2, 4, 41, 75) sampled the first leaf below and opposite the primary ear shoot (the seventh leaf according to Tyner's (81) description and photograph) from full silk to about 10 days after silking. Viets et al. (91) selected leaves at several growth stages but studied the second leaf below the ear at silking most intensively. The N content of the leaves declined as sampling was delayed but the correlation of yield with leaf N improved (r = 0.39, 0.89 and 0.97 for the first (June 17), second (July 9) and third (August 5, full silk) samplings, respectively).

Most investigators have advocated sampling at a definite physiological stage of growth but none has used silking dates (date when the corn is 50 or 75% silked) as a definite stage of maturity of corn. Shaw and Thom (70, 71) found that the length of the growth stage up to 75% silking varies considerably with environmental factors but the length of time from this date to physiological maturity is constant and independ-

ent of environment. None of the published research on time of sampling corn leaves has been comprehensive enough to use regressions of nutrient content on deviations from the silking date to adjust nutrient contents to a definite physiological stage of development such as the 75% silking date. It is not known whether deviations in the time of sampling over a week or two will contribute appreciably or not to the variance not explained by regression in correlation studies of yield or yield increases with leaf analysis.

A problem arises in leaf sampling corn with different fertilizer treatments. Dumenil and Shaw (24) found that fertilizers often hasten the maturity (75% silking date) of corn from a few days up to two weeks on low-fertility soils. Since it is impossible to sample all treatments at their 75% silking dates unless silking counts are being made, all treatments usually will be sampled at the same time.

The sensitivity in plant analysis may also vary with the chemical fraction of the nutrient analyzed. Most comparisons of N have been between total N and nitrate N. Few studies are available to make critical comparisons among different fractions of N for use in leaf analysis. Although Clements (18) used the total N of the sugar cane leaf blades for his N index, Burr (11) indicated that the alcohol-soluble N fraction of the stalks varied more with N treatment than did the total N and both varied more than the total N in leaf punches.

Chapman and Liebig (15) found that the nitrate concentration of leaves of orange seedlings varied 18 times while the total N increased 2.8 times from different N levels in solution cultures. Ulrich (85) found similar, less marked trends in sugar beet petioles. Differences among various fractions need to be determined in samples from field experiments and correlated with yields or yield increases in order to determine their relative sensitivities in predictions of yield responses to fertilizer.

Some researchers have claimed that the P soluble in 2% acetic acid provides a more sensitive index than total P for plant analysis. Ulrich (86) found that the acetic acid-soluble P in ladino clover petioles reflected the P status better than total P did. However, Viets et al. (91) found that acetic acid-soluble P in corn leaves was a linear function of and equal to about two-thirds of the total P over a wide range of concentrations. They concluded that the acetic acid-soluble P was no better index of P status than total P. Hanway and Pesek[1] found a similar relationship between the two quantities of P in corn leaves.

In the interpretation of plant analysis, Clements (18) has been the only one to use the moisture content of plant

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[1]Hanway, J. J. and Pesek, J. T. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

tissue (moisture index) for correlations with growth and levels of various nutrients. Since it is difficult to correlate the effect of moisture on plant composition and growth from the amount and distribution of rainfall and temperature, the relationship of plant moisture to composition may be useful in interpreting the effects of moisture stress on plant composition.

In summarizing the development and use of plant analysis, many factors have been shown to effect the relationship of plant composition with plant growth and yields or yield responses. Like soil analysis, plant analysis may save greatly in time and labor for diagnostic and prediction purposes. When comparing yield response predictions by plant and soil analyses, it must be remembered that much attention has been given in the past decades to the development and calibration of soil tests against field experiments. Little attention has been given to plant analysis for this purpose. Few have compared the two methods for predictions of yield responses to fertilizer over a range of conditions. Lundegårdh's (49) method of "triple analysis" included analyses of soil and subsoil samples as well as of plants. Later, when he found that little information was lost by omitting soil and subsoil analyses, he concentrated his attention on plant analysis.

Both Mitchell (53) and Lundegårdh (49) pointed out that the plant composition makes full allowance for the extent to

which plant roots penetrate and feed in different soil horizons. This cannot be done with soil analysis alone unless the root activity is determined in each horizon. Hanway[1] has found that the relative contribution to the plants' nutrition from the exchangeable K in each of several horizons can be determined by multiple regression analysis. From studies on the available P in the subsoil, Hanway[1] also found that it must be considered in interpreting soil tests.

Similarly, plant composition will integrate the different availabilities of different forms of the nutrient in the soil. Eid et al. (26) have shown the contribution of inorganic and organic forms of P to plant growth by the use of multiple regression. Likewise, Pratt (63) used multiple regression to estimate the contribution of exchangeable and non-exchangeable sources to the total K uptake by successive crops of alfalfa in pot experiments.

Black (5) has proposed a method of evaluating the nutrient availability in soils and predicting yield responses from fertilization. In this method the availability of one or more fractions at several depths would be determined by multiple regression using either dry matter yields or total nutrient uptake as the measure of plant response. He did not consider

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[1]Hanway, J. J. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

the more direct method of correlating yield responses with nutrient concentrations in the plants.

Since nutrient concentrations in the plant may be an index to the total availability of the soil nutrients in different horizons and of different chemical forms, the chemical composition of the plant may be useful in predicting yield responses to fertilizer, either used alone or along with soil tests.

III. EXPERIMENTAL PLANS AND PROCEDURES

Research on the direct application of fertilizers to corn in Iowa began in 1940 when experiments whose treatments were randomly assigned within replicates were initiated to determine the yield responses to P and K fertilizer applied with a planter attachment. In 1943 research on N fertilizers began. The major efforts with corn from 1943 to 1946 were directed towards determining profitable rates and ratios of hill or row fertilizers and profitable use of nitrogen. Most of the experiments with rates during this time involved a single variable with a basic, uniform application of the other nutrients.

These first few years of fertilizer experiments with corn (small grains and hay, as well) indicated that more information was needed on higher rates of all nutrients, effect of broadcast P and K fertilizers and effect of various combinations of broadcast and hill or row fertilizers. Experiments were started in 1947 using broadcast N, P and K in factorial combinations with hill or row fertilizer comparisons on the split plots. This type of experimentation has continued with emphasis on various combinations to study the interactions present and with much more emphasis on rates to characterize yield equations more fully.

At about this same time, increased interest in soil testing began. The yield response data since 1947 has been used

widely in making fertilizer recommendations during the past decade.

Corn leaf samples were first taken from an experiment on one of the experimental farms in 1947. In 1948, it was decided to collect leaf samples from the outlying fertilizer experiments in farmer-cooperators' fields to determine the effect of fertilizers on leaf composition and also to determine if leaf composition could be used to predict yield responses to fertilizer. From a small number of experiments with N rates in 1950, Bennett et al. (4) reported the first study of leaf composition in Iowa.

A. Experimental Sites, Field Procedures and Yield Estimates

Since the effect of broadcast P fertilizer on the leaf composition and yield of corn was of major interest in this study, 120 fertilizer experiments conducted from 1948 to and including 1956 had P fertilizer as a variable and leaf composition data available. Soil test data except for N soil tests also were available from these experiments. As will be discussed later, the number of experiments or treatments within the experiments was further reduced before final analyses.

These experiments were distributed over the state with most of them located in Soil Areas 1, 2, 3, 4, 7 (including Missouri bottomlands) and 8 (73). Information concerning the

experimental sites such as the name of the farmer-cooperator, county, year, soil type and past management is given in Table 40 in the Appendix. Soil types are those as described by Simonson et al. (73).

The experiments were conducted in farmers' fields. The experimental areas were tilled, planted and cultivated as the rest of the field except for the addition of the fertilizer. The areas varied in size from about one-third of an acre to more than one acre. Every attempt was made to locate the area in a uniform soil area of the same soil type. The varieties were the same as those planted in the rest of the field; consequently, many different hybrids were used. Some of the experimental areas were planted at a higher planting rate than the rest of the field but in most cases planting rates were the same. Stand levels, probably more than any other factor, limited yields of the higher rates of fertilizer.

The experimental designs were mostly randomized complete blocks. Most of the designs were NP, NPK and PK factorials but several included only P rates. The treatments were replicated two to six times. The levels of N, P or K including the zero level varied from two to nine in the data reviewed. Where experiments included four or more levels of two or three nutrients, three levels in the range of the other experiments were used; this was done to minimize the number

of treatments per experimental site. The experimental designs are given in Table 41 in the Appendix.

At 19 sites, time and methods of application as split-plot treatments were compared. Data from only the fall plowed-under and spring disked-in methods have been included. Stand level variables were also included at a few sites, either as whole-plot or split-plot treatments. At about one-third of the sites, a hill or row[1] fertilizer treatment was applied on the split plots at planting or at emergence. It was applied by the farmer's planter attachment at the same rate as the rest of the field or by a hand-applicator near the hill or drilled beside the seed. Where row fertilizer was not included as a variable, most of these sites received none although several received a uniform row application over the entire experimental area.

Rates of fertilizer were established by weighing the amount to be broadcast on each plot. The sources of fertilizer were ammonium nitrate (33.5-0-0), triple-superphosphate (0-45-0) and muriate of potash (0-0-60). The individual plots were 13.3 to 20 feet wide (4 to 6 rows) and 40 feet long in most cases. The fertilizers were broadcast by hand on the plots and either plowed under or disked in afterwards

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[1]Hereinafter, a hill or row fertilizer applied with a planter attachment or with hand equipment at or soon after planting will be referred to as row fertilizer.

at most sites, although the nitrogen was side-dressed at the time of the first or second cultivation at a few sites.

Soil samples were taken from the plow-layer at all sites before the fertilizer was applied. At least two separate samples were taken but one sample per replication was taken most frequently. Subsoil samples to a depth of 30 to 36 inches were also taken at about half of the locations. They were usually composited over two replications. Each surface and subsoil sample contained 8 to 15 composited sub-samples. Tests for pH and available N, P and K were made on the soil samples by the Iowa State College Soil Testing Laboratory according to the methods described by Hanway (36) and Hanway and Heidel (38). The soil test results are given in Table 41 in the Appendix.

Corn yields were estimated by harvesting and weighing the corn from two rows 25 to 35 feet long. In most cases, shelled corn samples were taken in the field from individual plots and weighed before and after drying at about 145°F. for 48 hours to determine the moisture content. From the moisture of the grain at harvest, yields were then calculated in bushels per acre of shelled corn at 15.5% moisture (No. 2 corn) using a standard conversion table. In a few cases, ear samples were taken from the individual plots, dried and shelled. From the moisture determination on the shelled corn, yields were calculated to shelled corn at 15.5% moisture. This lat-

ter method, although time-consuming, is the more accurate since it compensates fully for differences in shelling percentage due to treatment.

B. Methods of Leaf Sampling and Chemical Analysis

From 15 to 20 leaves (blade only) were removed from each plot in the experiments. The leaf selected for sampling was the first one below and opposite the primary ear shoot. According to Tyner's (81) description and photograph, this leaf was the seventh leaf from the base of the stalk. The leaves were randomly selected except that leaves showing mechanical damage were avoided as much as possible. The greatest cause of damage was corn borer which chewed the midrib at the junction of the blade and sheath, often causing the leaf to break at this point and hang down along the stalk. This damage occurred most frequently on the row fertilizer, P and NP treatments; these received a higher infestation of corn borers because of advanced maturity. It was difficult, sometimes impossible, to get undamaged samples in some fields. It is not known how much the corn borer damage affects the leaf composition, particularly treatment differences; likewise, this damage is also another unevaluated source of variation in yields. Other damage was splitting of the leaves by wind and, occasionally, some slight hail damage.

Most of the leaf samples were taken within 10 days of the 75% silking date. In a few fields, primarily in 1948 and 1953, the leaves were sampled up to two weeks after 75% silking. A few fields or treatments also were sampled before 75% silking. All treatments in an experiment were sampled on the same date. Theoretically, it would be desirable to sample all treatments in all experiments at a definite stage of maturity such as the 75% silking. This stage is easier to identify and better characterizes the stage of maturity than 100% silking. Silk emergence with time usually does not follow a normal distribution since emergence increases rapidly at the beginning but tails off more slowly at the end of the silking period. However, it is impossible to sample each treatment in widely scattered experiments at the same stage of development unless silking counts are being taken. The different stages of maturity of different experiments in an area, treatment effects on maturity from a few days up to two weeks on extremely nutrient-deficient fields and the competition from other work all contributed to the deviations in sampling times from the ideal time.

Considering the stage of development of all fields, the results from this study should best apply to corn leaf samples taken during the week immediately following 75% silking. Since N percentages in the leaf decrease with time, regression equations of N percentage as a function of time can be deter-

mined and used to adjust N levels to a constant maturity stage. Since P levels in the leaf appear to remain nearly constant from first silking to about 10 days after silking, variations in time of sampling within this period may have little effect on the results.

The leaf samples were air-dried within one to three days, later ground in a Wiley mill and stored in glass bottles for analysis. Total N, P and K in the leaves were determined in the Soil Fertility Laboratory[1]. Before analysis, the samples were dried at 65°C. for 24 hours. The Kjeldahl method was used for total N using mercuric oxide as a catalyst in the digestion with sulfuric acid. A 2-gram sample was used. In the P and K determination, a 0.5 gram sample was ashed in a muffle furnace at 400°C. The sample was then dissolved in nitric acid and made to volume. From an aliquot, P was determined by a modified Kitson and Mellon (43) procedure. The K was determined from another aliquot of solution with a Perkin-Elmer flame photometer using a solution of $LiNO_3$ as an internal standard. All results are reported as percentages of total N, P and K in the leaves on an oven-dry basis.

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[1]The analyses were made under the direction of Dr. J. J. Hanway according to procedures modified by him for use in these studies.

C. Statistical Procedures

The plot yields and stand levels of all experiments were analyzed by analysis of covariance according to Snedecor (74) and Cochran and Cox (20). Treatment yields in each experiment were adjusted to a mean stand level except in cases where fertilizer treatment had a significant effect on the stand levels.

The nutrient percentages were determined in the leaves from all of the treatments in each replication. Analysis of variance of treatment effects upon the nutrient percentages was not run. Therefore, unlike the mean treatment yields, the mean treatment nutrient percentages have not been adjusted to a mean stand level.

From the 120 fertilizer experiments, the data were selected to meet certain conditions as discussed in the next section. The yield and leaf composition means of the N and P fertilizer treatments from 93 experiments were used in the preliminary investigations and in the multiple regression analyses. There were 574 observations or treatment means included in the regression analyses for the percent P and yield and 474 observations included in the regression analyses for the change in percent P and change in yield. Since the relationships studied in the preliminary investigations involved certain N and/or P fertilizer treatments, the number of observations varied among the different regressions.

For the multiple curvilinear regression analyses, the data for all the variables associated with each treatment of each experiment were punched on IBM cards. The summary computations were done by the IBM 650 Computer by the Iowa State College Statistical Laboratory[1]. In the initial calculations, the machine calculated all the sums of squares and cross products corrected to the means, correlation coefficients, totals and means. The sums of squares and cross products of the selected variables then were punched on IBM cards and the matrix inverted by the IBM Computer. The partial regression coefficients also were calculated by the IBM 650 Computer and included in the output along with the inverse matrix. The standard errors of the partial regression coefficients, t tests of the regression coefficients and tests of significance of the reduction in residual error due to regression were calculated according to the methods given in Anderson and Bancroft (1). The final step was to determine the regression equation.

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[1]The author aknowledges the assistance of Dr. E. H. Jebe of the Statistics Department under whose supervision the regressions were calculated.

IV. RESULTS AND DISCUSSION

A. Selection of Data for Regression Analyses

Many factors affecting the N and P contents in the corn leaf and corn yield responses to N and P fertilizers were apparent in the large number of experiments. In order to limit the number of variables involved in the multiple regression analyses to the problems of primary interest, the data were selected to meet the following restrictions: (1) the K level was adequate in most cases and not seriously limiting yields, (2) drouth or insect damage was not seriously limiting yields and (3) only broadcast treatments without row fertilizer were used. Why these restrictions were made and which data were selected are discussed in the following paragraphs.

1. Adequacy of K

The relationships among N and P contents in the corn leaf and the responses to N and P fertilizer were affected markedly by K deficiency in several of the experiments. Since many of the experiments on the soils low in K included a K fertilizer variable, the magnitude of the yield responses to K indicated the degree of K deficiency. The K content in the corn leaves also indicated the degree of K deficiency present in the various fertilizer treatments. An approximate guide was the critical level of K in the corn leaf of 1.30% K on an air-dry

basis (about 1.4% K on an oven-dry basis) suggested by Tyner (81).

In 35 of the experiments where the soil tested medium to high in K, a K variable was not included and no uniform, basic K application was made. The K levels in the leaf were above the critical level in almost all cases and it was assumed that K was not limiting responses to N and P.

In 43 experiments where a K variable was included there were no interactions between K fertilizer and the other nutrients on yield and no apparent ones on leaf composition. Most of these showed only a small or no yield response to K and the leaf K contents were mostly at or above the critical level. The yields and leaf contents of the N and P treatments were averaged over all K levels, assuming additive effects of the N and P combinations and the K fertilizer. This doubled or tripled the observations per treatment mean.

A uniform K application was made on 11 experiments. All except four had leaf K levels above the critical level and only one was considerably below the critical level. This one (Experiment 55) was included although K may have been limiting yields somewhat. The data from this and other experiments are shown in Table 1.

Five experiments which were not complete factorials had leaf K levels below the critical level. Of the three experiments included, the responses to K were small. Since suf-

Table 1. Effects of K fertilizer on the yield and leaf composition responses due to N and P fertilizer treatments

Expt. and tmt. no.[b]	Fertilizer treatment[a] N	P_2O_5	K_2O	Yield (bu./A.)	Leaf composition %N	%P	%K
55-1	0	0	60	66.8	2.16	.205	1.04
2	40	0	60	70.9	2.20	.212	1.11
3	80	0	60	68.6	2.51	.221	1.15
4	0	80	60	78.2	2.08	.263	0.99
5	40	80	60	87.6	2.32	.278	0.87
6	80	80	60	94.5	2.54	.303	0.96
84-1,2	0, 60	0	0	58.8	3.04	.249	0.92
3,4	0, 60	60	0	76.8	2.93	.274	0.83
5,6	0, 60	0	30	75.0	2.99	.244	0.98
7,8	0, 60	60	30	75.8	2.90	.270	0.96
9,10	0, 60	0	60	75.0	2.91	.242	1.18
11,12	0, 60	60	60	82.8	2.86	.257	1.28
112-1-3	0, 40, 80	0	0	105.2	3.01	.258	1.04
4-6	0, 40, 80	40	0	112.5	2.91	.269	1.07
7-9	0, 40, 80	0	40	117.0	2.79	.254	1.18
10-12	0, 40, 80	40	40	119.4	2.83	.266	1.18
87-1,2	0, 60	0	0	78.8	3.08	.251	1.51
3,4	0, 60	60	0	90.4	3.19	.278	1.68
5,6	0, 60	0	30	86.6	3.06	.261	1.66
7,8	0, 60	60	30	89.3	3.22	.286	1.68
9,10	0, 60	0	60	91.7	3.16	.282	1.81
11,12	0, 60	60	60	97.8	3.03	.277	1.76
120-1	0	0	0	88.3	2.48	.208	1.22
2	150	0	0	93.9	2.76	.200	1.06
3	0	90	0	81.4	2.27	.206	0.86
4	150	90	0	89.5	2.70	.248	1.02
5	0	0	90	98.4	2.48	.205	1.42
6	150	0	90	91.4	2.63	.206	1.58
7	0	90	90	76.9	2.18	.210	1.60
8	150	90	90	123.9	2.65	.250	1.41

[a]Rates of N, P_2O_5 and K_2O in pounds per acre.

[b]Two or three treatment numbers together show that P and K treatments were averaged over all N levels.

Table 1. (Continued)

Expt. and tmt. no.	Fertilizer treatment N	P_2O_5	K_2O	Yield (bu./A.)	Leaf composition %N	%P	%K
82-1,2	0, 60	0	0	60.2	3.29	.238	0.82
3,4	0, 60	60	0	68.2	3.33	.296	0.79
5,6	0, 60	0	30	78.8	3.11	.234	1.08
7,8	0, 60	60	30	95.8	3.20	.304	0.98
9,10	0, 60	0	60	82.2	3.14	.228	1.24
11,12	0, 60	60	60	105.0	3.19	.294	1.17
45-1[c]	0	0	0	55.3	3.02	.219	0.71
2	0	40	0	59.3	3.10	.317	0.57
3	0	80	0	51.3	3.07	.358	0.74
4	0	0	40	90.7	3.09	.219	1.13
5	0	40	40	101.7	2.99	.271	0.98
6	0	80	40	103.0	3.12	.313	1.05
7	0	0	80	91.0	2.99	.225	1.35
8	0	40	80	111.7	2.85	.260	1.29
9	0	80	80	114.7	3.06	.283	1.27
1	0	0	0	55.3	3.02	.219	0.71
2	0	40	0	49.0	3.10	.293	0.63
3	0	80	0	57.0	3.07	.333	0.69
4	0	0	40	97.3	3.09	.215	1.13
5	0	40	40	93.7	2.99	.273	0.95
6	0	80	40	93.3	3.12	.303	0.82
7	0	0	80	91.3	2.99	.215	1.35
8	0	40	80	104.7	2.85	.248	1.23
9	0	80	80	102.3	3.06	.260	1.11

[c]First 9 treatments were broadcast and plowed under; second 9 treatments were broadcast and disked in.

ficient treatments with K fertilizer were not included to obtain the N and P effects with K, the N and P fertilizer treatments without K were used.

Of the remaining 26 experiments, all of which had a K variable, the yields and leaf contents of the N and P treatments at one or more levels of K fertilizer were used because

of NK, PK, or NPK interactions. In these, the yield response-leaf composition relationship was different at the various K levels. In three fields, Experiments 78 to 80, where the K levels in the soil and leaf were high, the N and P treatments at K_0[1] or averaged over K_0 and K_1 were used because of negative PK interactions. In five experiments where K levels were low, the N and P treatments without K were used because of negative PK interactions. The cause of most of these negative interactions probably was due to another limiting factor, inadequate stand level, which prevented the responses to P and K from being additive. The data from two of these, Experiments 84 and 112, are also shown in Table 1. Although K fertilizer usually decreased the leaf P content in the low-K fields, there was an exception in Experiment 87 in which a negative PK interaction occurred because the K fertilizer increased the leaf P content (Table 1).

In 18 experiments which were on K-deficient soils, positive NK, PK or NPK interactions occurred. The N and P fertilizer effects were smaller without K (or negligible in extreme cases) than with K fertilizer. The yields and leaf composition of the N and P treatments with K fertilizer then were used. The data from Experiment 120 are shown in Table 1 to illustrate a positive NPK interaction on yield. Where three

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[1]Subscripts 0, 1 and 2 to the elemental symbols refer to the 0, 1st and 2nd levels of the element, respectively.

levels of K were present, the yields and leaf contents of the N and P treatments were averaged over the two rates of K fertilizer in most cases. The initial rate usually raised the leaf K level to or above the critical level or the responses to N and P were not much different at the two rates of K. The data from Experiment 82 in Table 1 illustrate a positive PK interaction. In four fields, three of which had a basic row application, the N and P treatments at the highest K level were used. The data from Experiment 45 in Table 1 illustrate the marked, positive PK interaction on yields and the effect of methods of application on this interaction.

The K level (or levels) of the N and P treatments are given in Table 41 in the Appendix. The yields and N and P contents in the leaf of the treatments in each experiment used in the final regression analyses are given in Table 42 in the Appendix.

2. Drouth and other effects

The selection of experiments where drouth was not seriously limiting yields was difficult since there was no way to establish adequately the occurrence of drouth at any particular experimental site. Since summer rainfall often has not been uniform within an area, rainfall records at a nearby weather station usually were inadequate for any particular site. It would have been preferable, of course, to enter

weather variables into the regression equations. In most recent years, there have been areas in the state where lack of moisture at certain times during the growing season limited yields and responses to fertilizer. Therefore, the data were not restricted too severely with regard to drouth effects since the results of this study are to be applied to the majority of conditions and years.

Generally, dry weather reduced yields and the uptake of nutrients, particularly that of N, from the fertilizers. The experiments that were excluded because of severe drouth effects were Experiments 75, 76, 95, 96, 97, 105, 106, 108, 117, and 118. The yields and leaf composition of the treatments from these experiments are given in Table 43 in the Appendix. Others which were affected somewhat by drouth but not excluded were Experiments 15, 16, 49, 72, 78 and 79.

Corn borer damage was particularly severe in Experiment 22 which was eliminated. Others had varying amounts of corn borer damage but none was eliminated. Two, Experiments 52 and 76, had severe rootworm damage which was accentuated by drouth; the data from these were not used. Three, Experiments 41, 80 and 104, were eliminated because of high soil variability, little of which was eliminated by the replications. The data from all of these experiments are given in Table 43 in the Appendix.

3. Row fertilizer effects

A row fertilizer variable was included in 42 experiments. Most of the row fertilizers were complete N, P and K fertilizers although a few contained only N and P. The average rate per acre supplied 6.1, 24.4 and 19.8 pounds per acre of N, P_2O_5 and K_2O, respectively. The average responses were 9.7 bushels per acre and -0.06% N, 0.003% P and 0.04% K in the corn leaves.

Although the average responses of the N, P and K percentages in the leaf to row fertilizer application were small, the relationships between the yield response to row fertilizer and the leaf N and P contents were investigated. These relationships were studied on the treatments without broadcast N or P fertilizer (N_0P_0 treatments).

There was no relationship between the yield response to row fertilizer and initial percent P in the corn leaf as shown in Figure 1. The correlation between the response to row fertilizer and soil test P level in the plow-layer was negative but not significant at the 5% level[1] (Figure 2). There was no relationship between the response to row fertilizer

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[1]Hereinafter, the .05 or .01 significance probability level, Anderson and Bancroft (1), will be designated as the 5% or 1% level. The terms "significant" and "highly significant" refer to the 5% and 1% level, respectively. In the tables and figures, these levels will be designated by * and **, respectively.

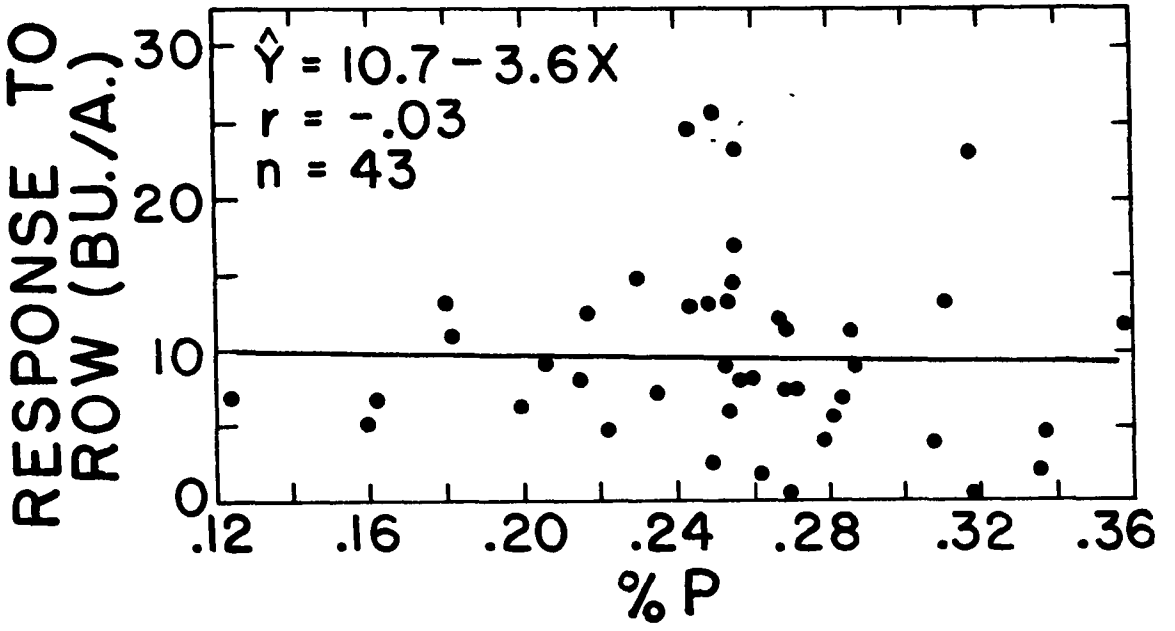

Figure 1. Regression of corn yield response to row fertilizer on the percent P in the corn leaf without row fertilizer

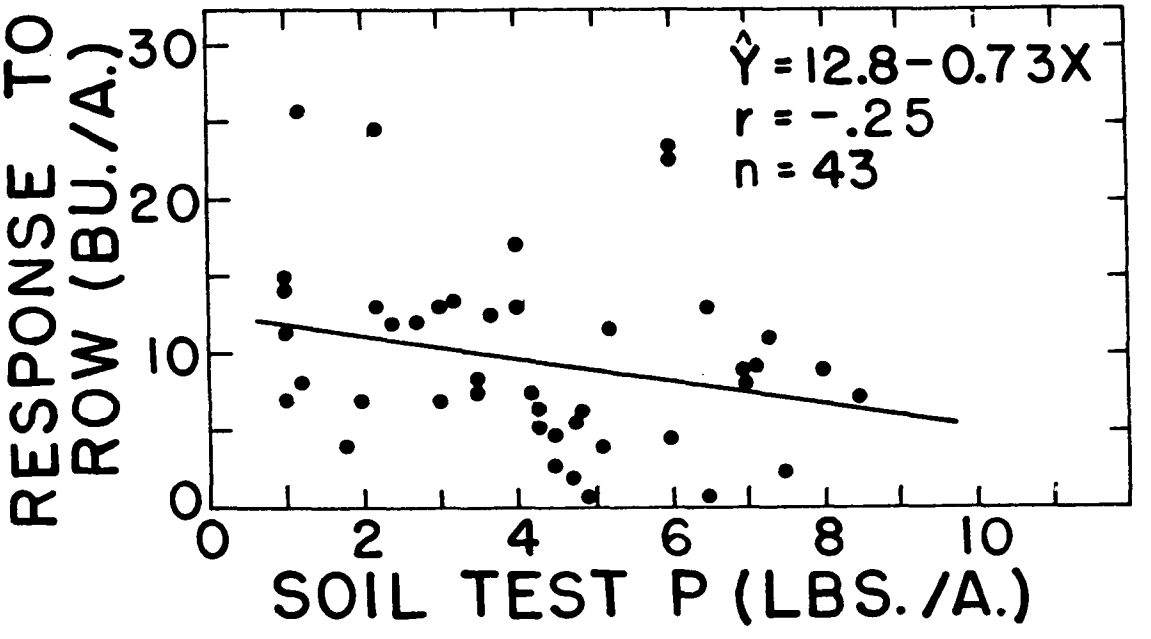

Figure 2. Regression of corn yield response to row fertilizer on the soil test P in the plow-layer

and the change in percent P in the corn leaf due to row fertilizer application (Figure 3). The lack of increase in leaf P due to row fertilizer in these experiments agrees with the results of Webb[1]. A negative relationship, but not significant at the 5% level, existed between the response to row fertilizer and change in percent N due to row application (Figure 4). However, the effects of the individual nutrients were confounded in all of these comparisons. Eliminating four of the largest responses which were due in part to K might have changed the relationships considerably.

It appears that leaf composition at time of silking will not be useful to determine the effects of row fertilizer applied with a split-boot attachment or to predict its effect on yield.

Of more interest in these experiments is the effect of row fertilizer on the relationship between the yield response[2]

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[1]Webb, J. R. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

[2]The yield or leaf composition response to broadcast P without or with N fertilizer is the difference between the N_0P_r and the N_0P_0 treatments (N_0P_r - N_0P_0) or the difference between the N_rP_r and corresponding N_rP_0 treatments (N_rP_r - N_rP_0), respectively. Conversely, the response to N fertilizer without or with P fertilizer is N_rP_0-N_0P_0 or N_rP_r-N_0P_r, respectively. The subscript "r" refers to all rates (all levels except the zero level) of the fertilizer nutrient. The responses to N and P include those to all rates unless the responses to individual rates or levels are designated. In the figures and tables, N_0 and N_r or P_0 and P_r designate without

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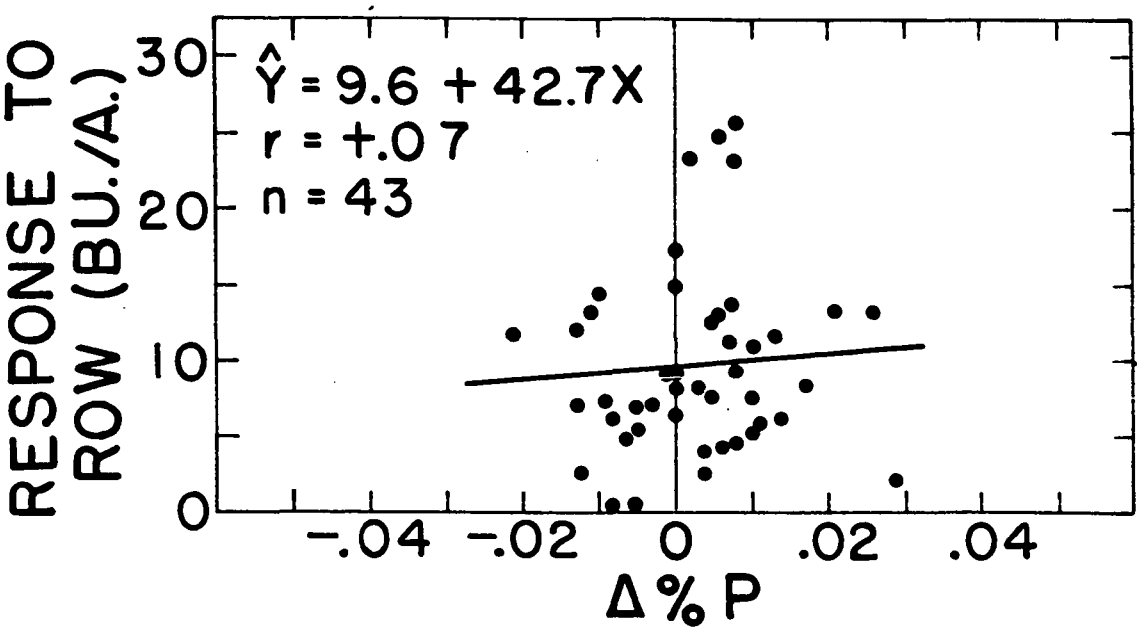

Figure 3. Regression of corn yield response to row fertilizer on the change in percent P in the corn leaf due to row fertilizer

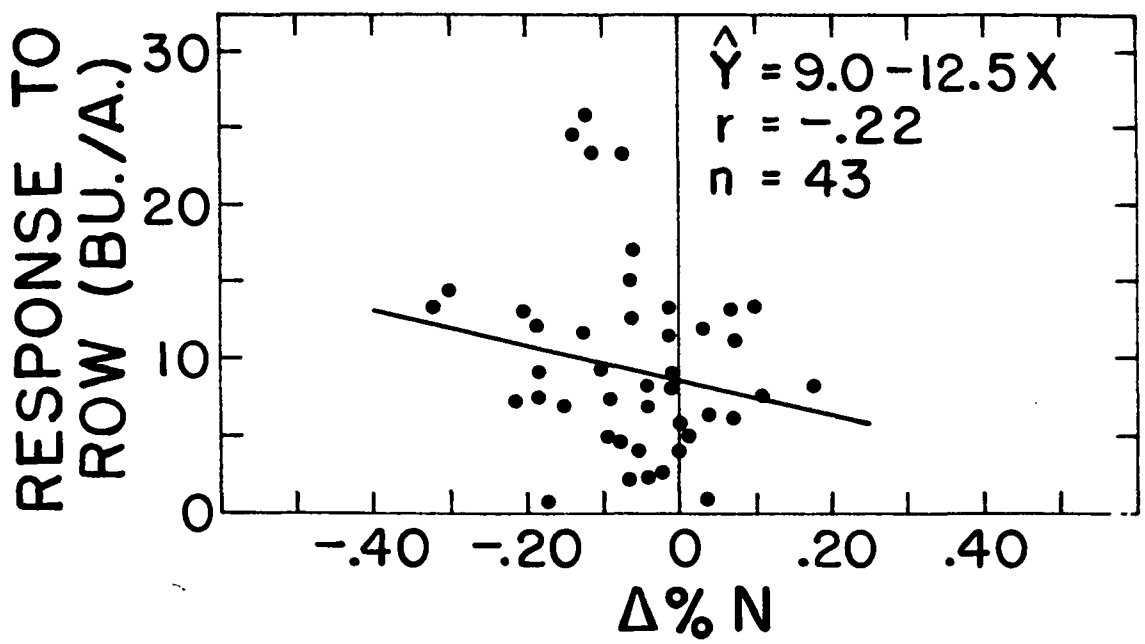

Figure 4. Regression of corn yield response to row fertilizer on the change in percent N in the corn leaf due to row fertilizer

to broadcast P and the percent P in the corn leaf. These relationships are shown in Figure 5 (without N) and Figure 6 (with N fertilizer). The linear regression equations without and with row fertilizer indicated similar slopes but different elevations at each of the N levels. The mean yield responses to P without N were 5.9 and 2.3 bushels per acre without and with row fertilizer, respectively. With N, the responses to P were 8.7 and 5.5 bushels without and with row fertilizer, respectively.

The differences between the regression coefficients and adjusted means of these relationships were tested according to the method[1] given by Snedecor (74). These tests are shown

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and with N fertilizer or without and with P fertilizer, respectively. The "r" used as a subscript should not be confused with the correlation coefficient, r.

[1]Linear regressions may differ in variance, slope and elevation. Homogeneous variance will be assumed in the relationships. The difference between or among the slopes of the regressions are tested as follows: (1) the degrees of freedom and the sums of squares of the deviations from regression of the individual regressions are pooled to obtain the "Within" sum of squares, (2) the sums of squares and products of the individual regressions are pooled to form a "Common Regression" whose slope is the weighted average of the slopes of the individual regressions, (3) the difference between the "Common" and "Within" sums of squares measures the difference between or among the individual regression coefficients and (4) the test of the hypothesis that the regression coefficients are equal is made by comparing the ratio of the mean square for "Regression Coefficients" to the mean square for "Within" with the tabular F at the appropriate degrees of freedom.

The test of the difference in the elevation of the regression lines may have little meaning unless the lines are
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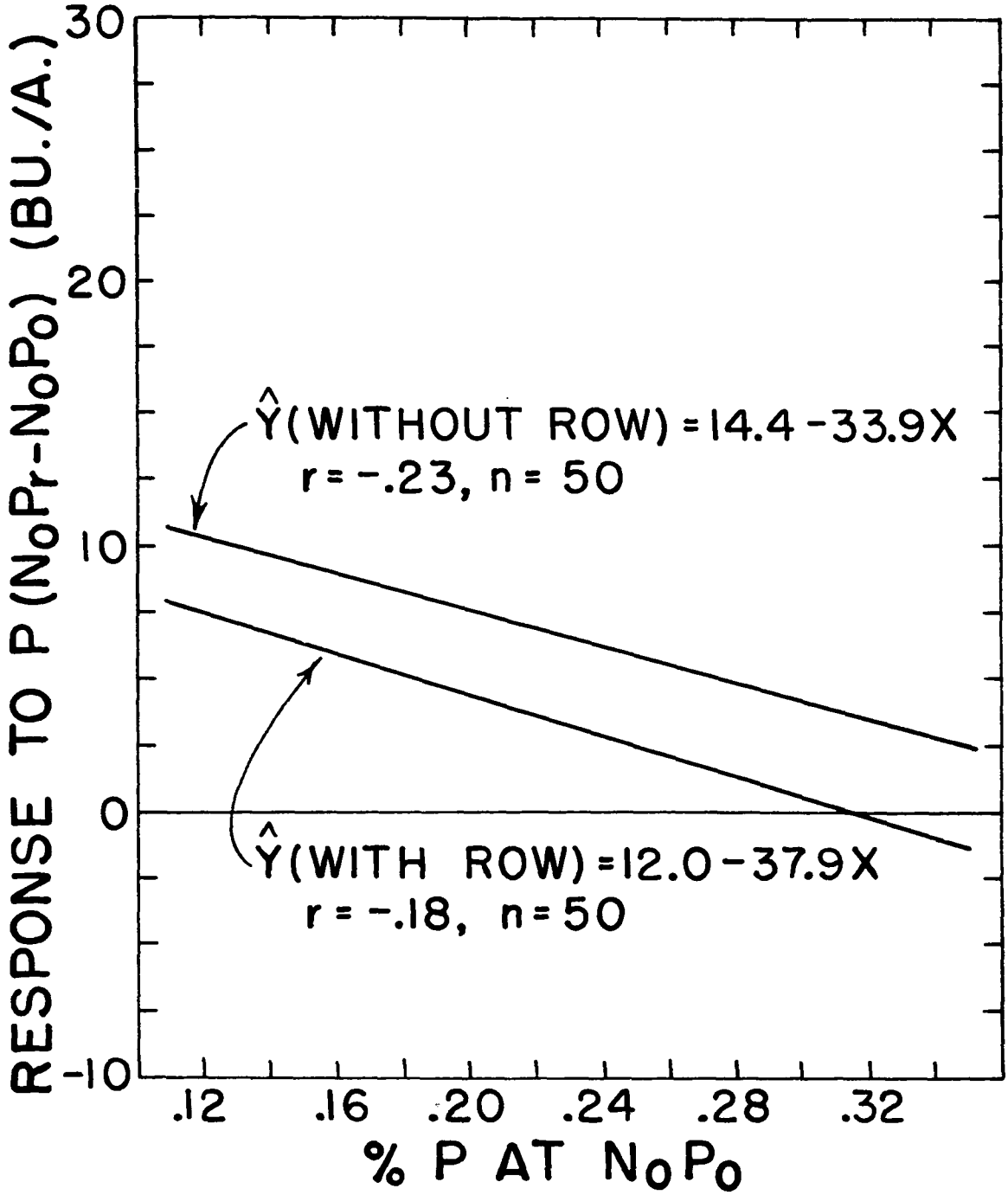

Figure 5. Regressions of the corn yield response to broadcast P fertilizer, without and with row fertilizer, on the percent P in the corn leaf at N_0P_0 (all P rates, without N fertilizer)

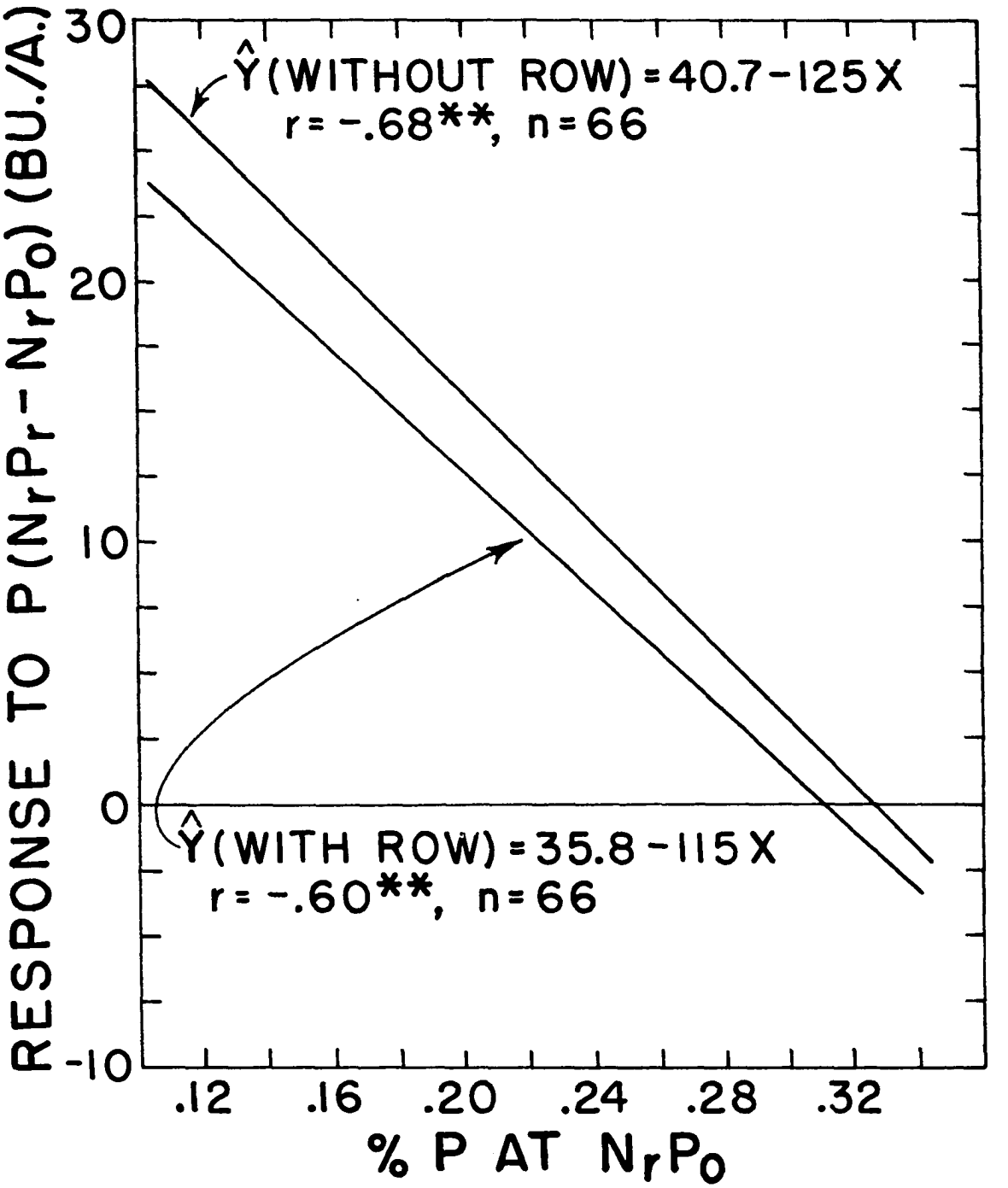

Figure 6. Regressions of the corn yield response to broadcast P fertilizer, without and with row fertilizer, on the percent P in the corn leaf at N_rP_0 (all P rates, with N fertilizer)

in Table 2. There was no significant difference between the regression coefficients either without or with N. Without N, the adjusted means of the responses to P, without and with row fertilizer, were significantly different at about the 2% level. With N, the adjusted means were not significantly

Table 2. Tests of significance between the regression coefficients and the adjusted means in the relationships between response to P and percent P in the corn leaf, without and with row fertilizer

Regressions	Source of variation	d.f.	M.S.	F
Without N (Figure 5)	Within	96	48.28	
	Reg. Coef.	1	3.30	0.07
	Common	97	47.81	
	Adj. Means	1	307.25	6.43*
With N (Figure 6)	Within	128	49.79	
	Reg. Coef.	1	7.29	0.15
	Common	129	49.46	
	Adj. Means	1	152.70	3.09[a]

[a]Significant at the 8.5% level.

different at the 5% level but were different at the 8.5% level. The row fertilizer had little effect on the leaf P content but did reduce the response to broadcast P fertilizer at any leaf P level.

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parallel. The difference between the "Total" sum of squares (all of the samples combined) and the "Common" sum of squares is the sample difference in elevation, the "Adjusted Means". The test of the hypothesis that the regression lines have the same elevation is made by comparing the ratio of the mean square for "Adjusted Means" to the mean square for "Common" with tabular F at the appropriate degrees of freedom.

Since the presence of row fertilizer affected the relationship between the yield response to broadcast P fertilizer and leaf P composition, the row fertilizer treatments from the experiments which had this variable and the experiments which had a uniform row application were omitted from the multiple regression analyses. The experiments with uniform row applications were Experiments 13, 32, 44, 48, 69, 70, 92, 100, 103 and 115. The data from the treatments with row fertilizer and the experiments with a uniform row treatment are given in Table 43 in the Appendix.

B. Preliminary Examination of the Relationships

It was necessary to determine the simple relationships among the various factors and the P composition of the corn leaf, the corn yields and the yield responses before formulating the mathematical models for the regression analyses. First, the simple linear correlation coefficients and regression equations were calculated for many of the relationships. Next, the approximate relationships were determined by the method of "successive group means"[1] according to Ezekiel (29).

[1]The range of the observations of the X variable was arbitrarily divided into successive groups or sub-ranges. From the observations within each of the groups, the means of the X variable and associated Y variable were calculated. These means were plotted in the figures so that they could be compared with the linear regression. The limits of the groups of the different X variables are uniform in most of the figures. The group limits are marked in the figures by lines on the X-axis; wide lines are used if lines marking the units of (footnote continued on following page)

The deviations from linear regression in the relationships thus could be visually estimated. Most of the relationships were determined without and with N or P fertilizer in order to determine the nature and extent of the interactions among the fertilizers and the other factors.

1. Change in percent P

Although the regression of corn yield response to N and P fertilizers on the composition of the corn leaf is of most interest in this study, the effects of fertilization on the leaf composition also must be understood. The importance of understanding the factors affecting the leaf P content is emphasized by the high correlation between the yield response to P fertilizer and the change in the leaf P content due to P fertilization.

The regressions of the yield response to P on the change in the percent P in the corn leaf due to P fertilizer were positive and linear (Figure 7). The mean yield responses to P without and with N fertilizer were 6.8 and 14.9 bushels per acre, respectively. The mean changes in percent P due to P

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the X variable are also present. In the interpretation of these group means, it must be remembered that the selection of the sub-ranges may influence the apparent shape of the curve and that unequal frequencies of the observations within the groups, particularly at the extremes, may cause an apparent lack of agreement with the linear regression.

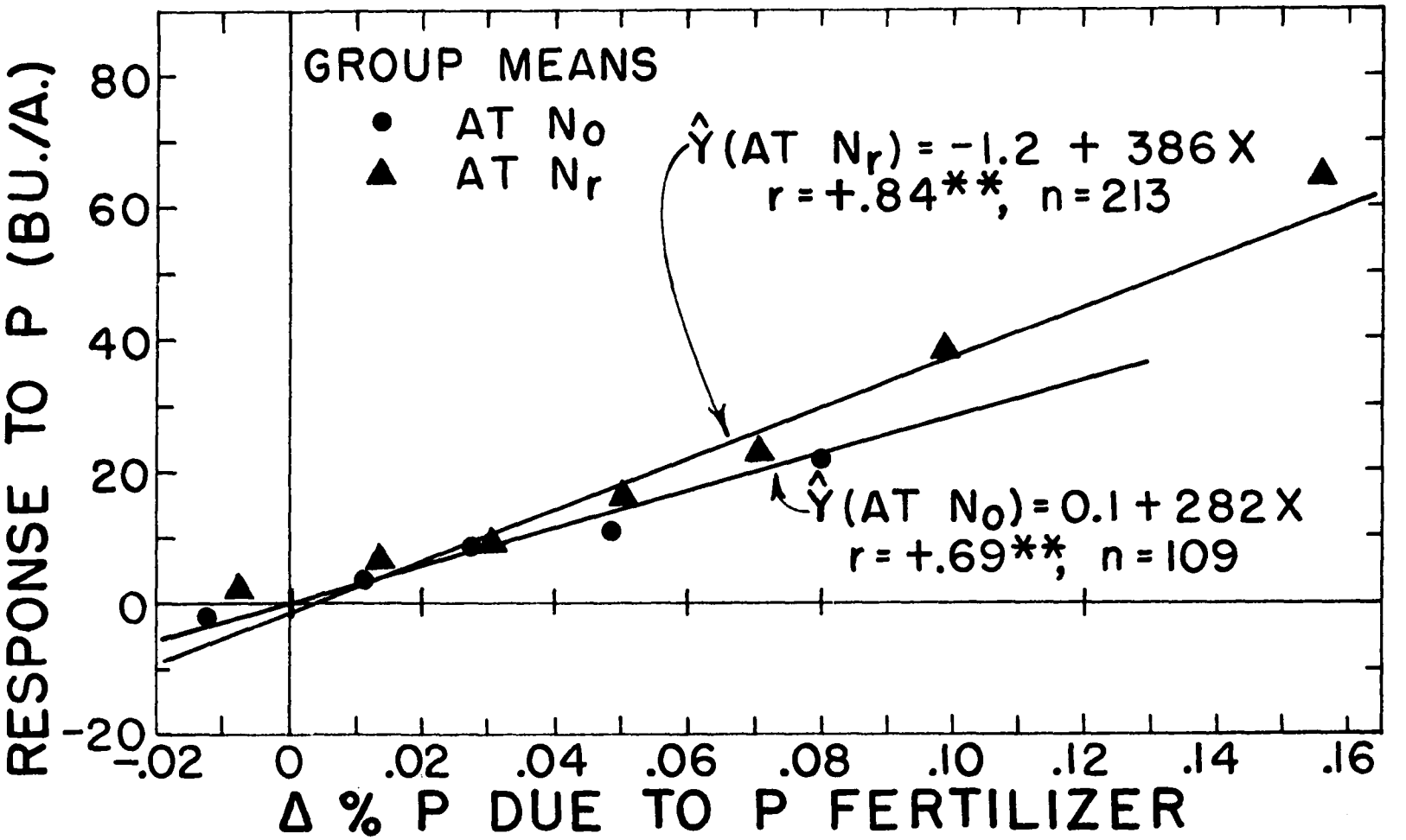

Figure 7. Regressions of the corn yield response to broadcast P fertilizer, without and with N fertilizer, on the change in percent P in the corn leaf due to P fertilizer (all P rates)

fertilizer without and with N were 0.024 and 0.042% P, respectively. These highly significant differences in the responses to P fertilizer without and with N show a NP fertilizer interaction on both the yield response and the change in leaf composition.

The difference between the regression coefficients without and with N, as shown in Figure 7, was highly significant but the difference between the adjusted mean responses to P without and with N was not significant (Test 1, Table 3). The difference between the regression coefficients indicates that the yield response to P is somewhat larger at an equal change in the leaf P content in the presence than in the absence of N fertilizer. The nonsignificant difference between adjusted yield response means but significant difference between unadjusted response means, without and with N, indicates that the NP interaction on yield response is due mostly to the greater uptake of P from the P fertilizer rather than to the larger yield response at a constant change in the leaf P.

The following factors affecting the change in the leaf P content were investigated: the P and N availability in the soil, P and N fertilizer levels, NP fertilizer interaction, interactions of N and P fertilizers with the N and P availabilities in the soil, stand level and methods of P fertilizer application.

Table 3. Tests of significance between or among the regression coefficients and adjusted means in the relationships involving the change in the percent P in the corn leaf due to P fertilizer

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Response to P on change in percent P, at N_0 and N_r (Fig. 7)	Within	318	70.0	
		Reg. Coef.	1	533.5	7.6**
		Common	319	71.5	
		Adj. Means	1	172.2	2.41
2.	Change in percent P on Check percent P, at N_0 and N_r (Fig. 8)	Within	318	.00078	
		Reg. Coef.	1	.01154	14.7**
		Common	319	.00082	
		Adj. Means	1	.02116	25.8**
3.	Change in percent P on Check percent P and percent P of the N_rP_0 treatment, at N_r	Within	422	.00083	
		Reg. Coef.	1	.00113	1.36
		Common	423	.00083	
		Adj. Means	1	.00032	0.38
4.	Change in percent P due to different P rates on the percent P of the N_rP_0 treatment, at N_r (Fig. 9)	Within	205	.00053	
		Reg. Coef.	3	.00648	12.2**
		Common	208	.00062	
		Adj. Means	3	.00984	15.9**
5.	Change in percent P on soil test P, at N_0 and N_r (Fig. 10)	Within	318	.00066	
		Reg. Coef.	1	.06137	93.5**
		Common	319	.00085	
		Adj. Means	1	.02003	23.6**
6.	Change in percent P on Check percent N, at N_0 and N_r (Fig. 11)	Within	318	.00104	
		Reg. Coef.	1	.00476	4.59*
		Common	319	.00105	
		Adj. Means	1	.02310	22.0**
7.	Change in percent P on Check percent N and percent N of the N_rP_0 treatment, at N_r	Within	422	.00123	
		Reg. Coef.	1	.00689	5.60*
		Common	423	.00124	
		Adj. Means	1	.00261	2.09

The P availability in the soil was estimated from the Check[1] percent P in the corn leaf or from the percent P in the leaf of the N_rP_0 treatment and from the soil test P in the plow-layer and subsoil. A single value for the soil test P in the subsoil was obtained by averaging the test values from the soil layers between 1 and 2 and 2 and 3 feet. Subsoil samples were taken in about half of the experiments and values were estimated from soil type means for the rest. The soil test P in the subsoil has been found to be fairly uniform within soil types[2]. Since a knowledge of the P availability in the subsoil has been necessary to predict yield responses to P fertilizer from the soil test P in the plow-layer, the importance of the subsoil P availability was considered great enough to include it as a variable although it had to be estimated in many cases. If the subsoil P is not included as a variable, the data might have to be grouped within a soil association area (or areas) for the regression analyses.

The change in the percent P due to P fertilizer and the Check percent P in the corn leaf were negatively and significantly correlated and the relationship appeared to be linear without N but curvilinear with N fertilizer (Figure 8). The

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[1]Hereinafter, the percent P or percent N in the corn leaf of the N_0P_0 treatment will be designated as Check percent P or Check percent N.

[2]Hanway, J. J. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

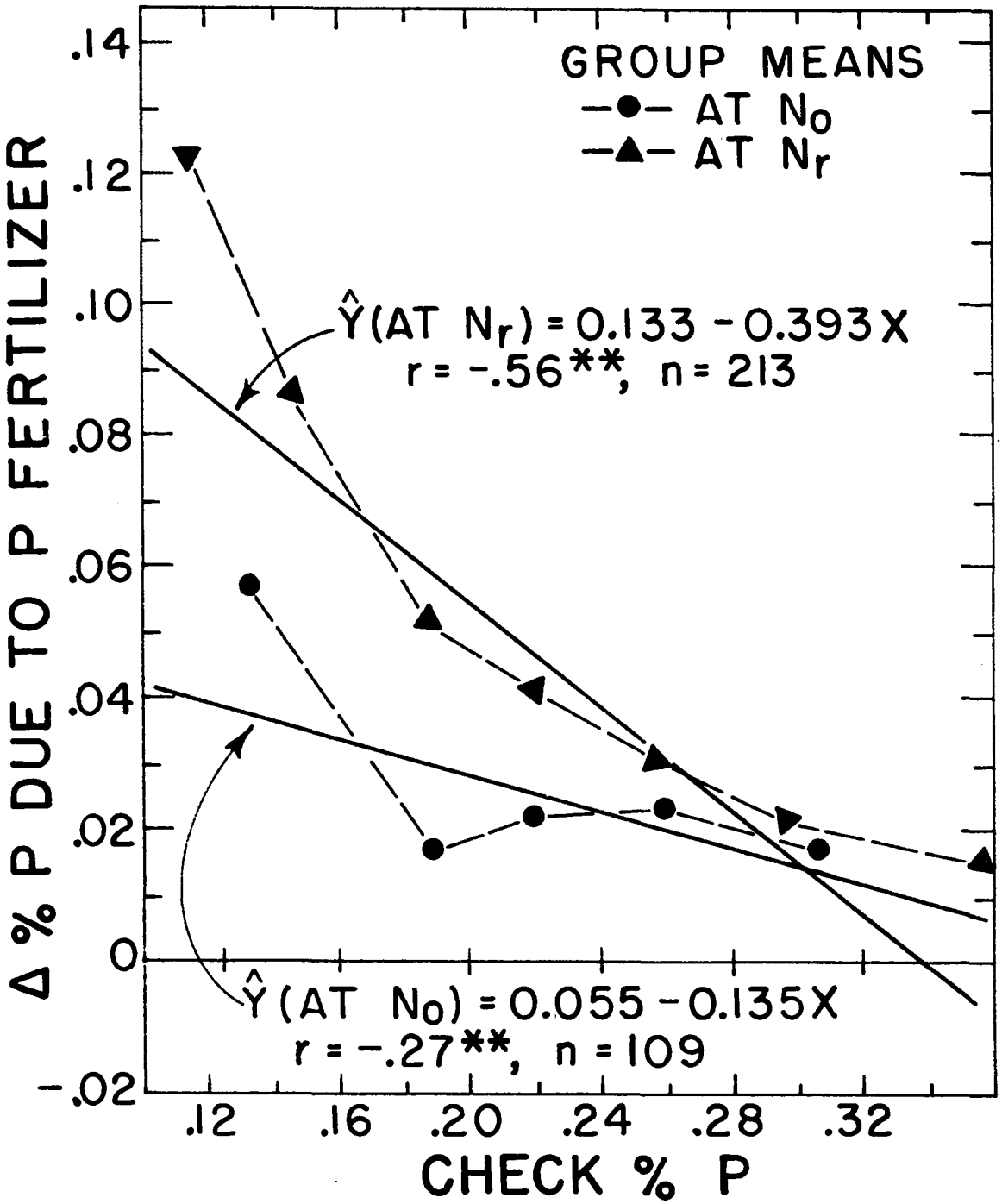

Figure 8. Regressions of the change in percent P in the corn leaf due to P fertilizer, without and with N fertilizer, on the Check percent P in the corn leaf (all P rates)

correlation between the two was considerably higher with N than without N fertilizer. The highly significant difference between the slopes of the regressions without and with N (Test 2, Table 3) indicates a N fertilizer x Check percent P interaction on the change in percent P due to P fertilizer. The difference in the adjusted means without and with N shows a NP fertilizer interaction on the change in percent P due to P fertilizer.

Since the percent P in the corn leaf at the N_rP_0 treatment also can be considered as an estimate of the P availability in the soil when N fertilizer is present, the regression of the change in the percent P due to P fertilizer on the percent P at N_rP_0 was also determined and was: $\hat{Y} = 0.149 - 0.456X$. This relationship was not significantly different from the one between the change in percent P, with N fertilizer, and Check percent P (Test 3, Table 3). The change in percent P is more highly correlated with the percent P at N_rP_0 ($r = -0.66^{**}$) than with the Check percent P ($r = -0.56^{**}$) because the effect of the N fertilizer on the change in the percent P in the leaf is included in the former but is not included in the latter relationship.

The regressions of the change in percent P in the corn leaf due to different rates of P fertilizer on the percent P at the N_rP_0 treatment are shown in Figure 9. The differences among the regression coefficients and the adjusted means of

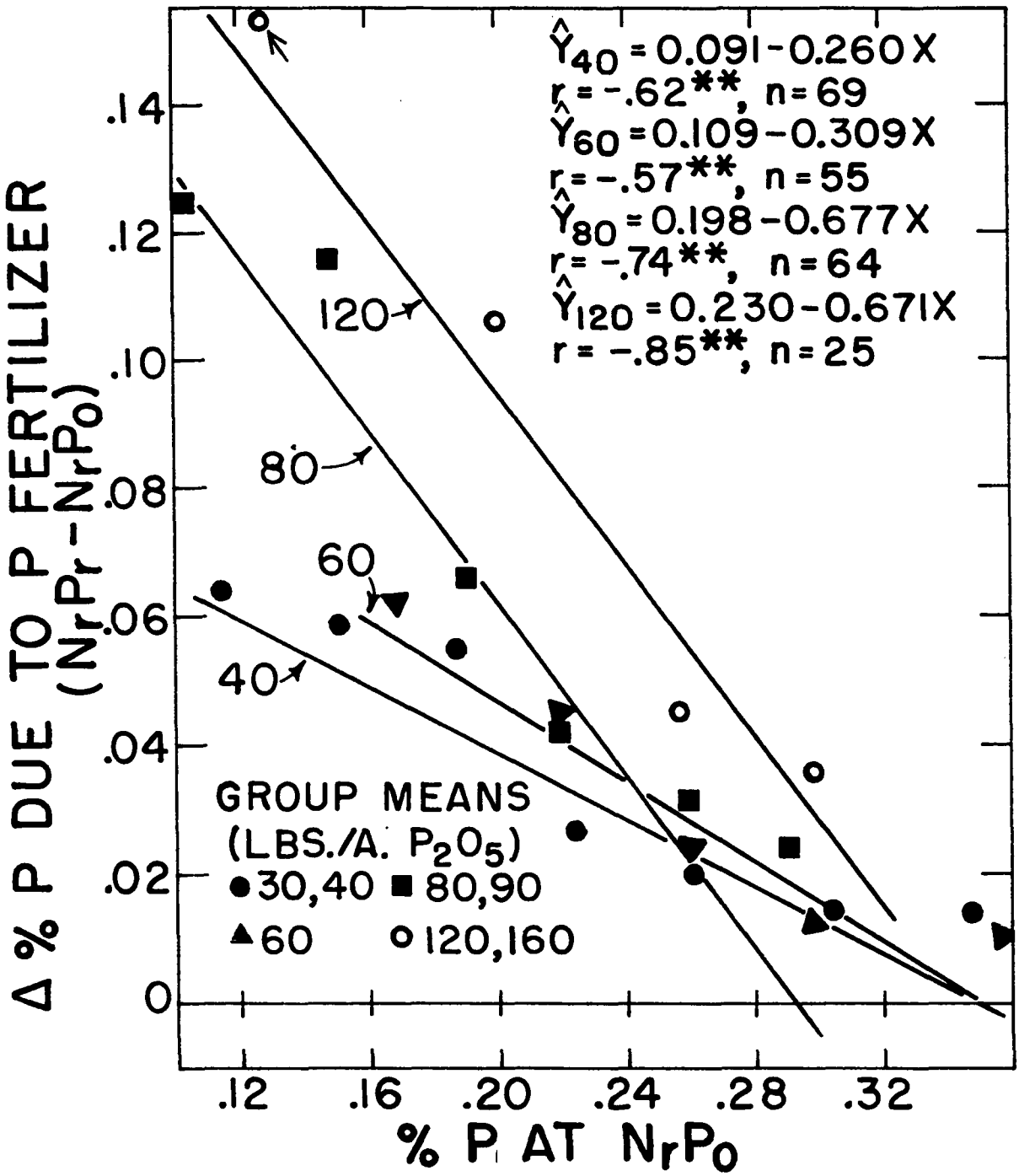

Figure 9. Regressions of the change in percent P in the corn leaf due to rates of P fertilizer on the percent P in the corn leaf at N_rP_0 (with N fertilizer)

the change in percent P were highly significant among the various P rates (Test 4, Table 3). The highly significant differences among regression coefficients, which show that the effect of different P rates on the change in the percent P varies with the initial leaf P level, indicate a P fertilizer x initial percent P interaction on the change in percent P due to P fertilizer.

The change in the percent P in the corn leaf due to P fertilizer and the soil test P level, without and with N fertilizer, were significantly and negatively correlated (Figure 10). The relationship appeared to be linear without N but curvilinear with N fertilizer. The highly significant difference between the regression coefficients (Test 5, Table 3) indicates a N fertilizer x soil test P interaction on the change in percent P due to P fertilizer.

Without N fertilizer, the correlation between the change in percent P and soil test P ($r = -0.37^{**}$) was higher than the one between the change in percent P and leaf percent P ($r = -0.27^{**}$). With N fertilizer, the coefficients of determination, r^2, of the change in percent P on soil test P, Check percent P in the leaf and percent P in the leaf at N_rP_0 were 0.25, 0.31 and 0.43, respectively. The coefficients of determination probably overestimate the differences among these relationships since the relationship of the change in percent P in the leaf with the soil test P appears to be more curvi-

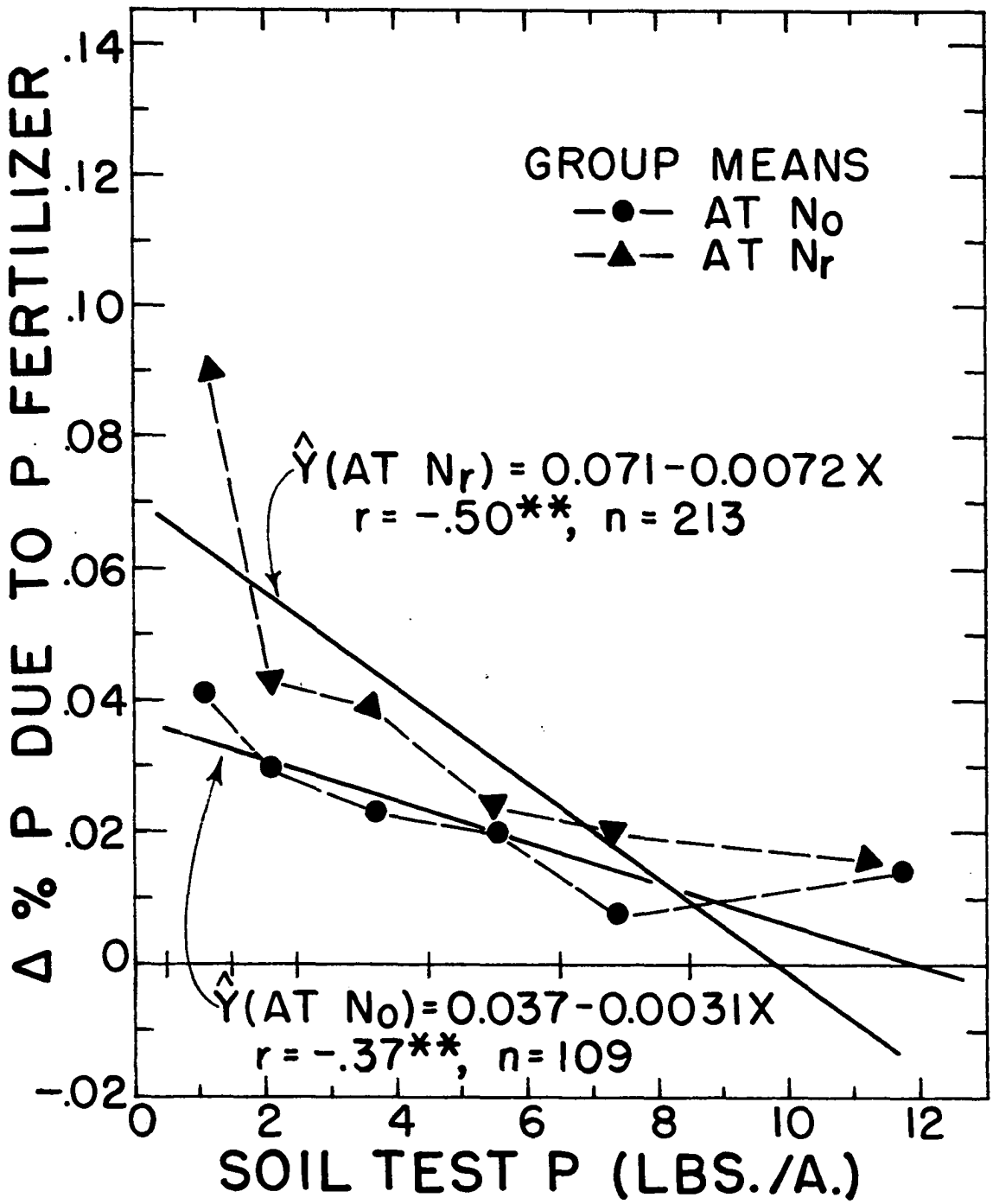

Figure 10. Regressions of the change in percent P in the corn leaf due to P fertilizer, without and with N fertilizer, on the soil test P in the plow-layer (all P rates)

linear than the ones with the initial percent P in the leaf. The comparison of leaf P and soil test P for predicting the change in the percent P in the leaf due to P fertilizer shows little difference between the two methods if the Check percent P in the leaf is used. If the effect of N fertilizer on the percent P is known or can be estimated, the change in the percent P may be predicted with more precision from the leaf P than from the soil test P.

Since N soil tests were not available from all the experimental sites, the N availability in the soil had to be estimated from the Check percent N in the corn leaf. On the fertilized treatments, the percent N in the leaf also indicated the additional effects of the N and P fertilizers.

There was no relationship between the change in percent P due to P fertilizer and the Check percent N in the leaf without N fertilizer, but the relationship between the two was negative, linear and significant with N fertilizer (Figure 11). The significant difference between the regression coefficients without and with N (Test 6, Table 3) indicates a N fertilizer x Check percent N interaction on the change in percent P due to P fertilizer. If the Check percent N in the leaf reflects the N availability in the soil, there is a N fertilizer x available soil N interaction on the change in the percent P.

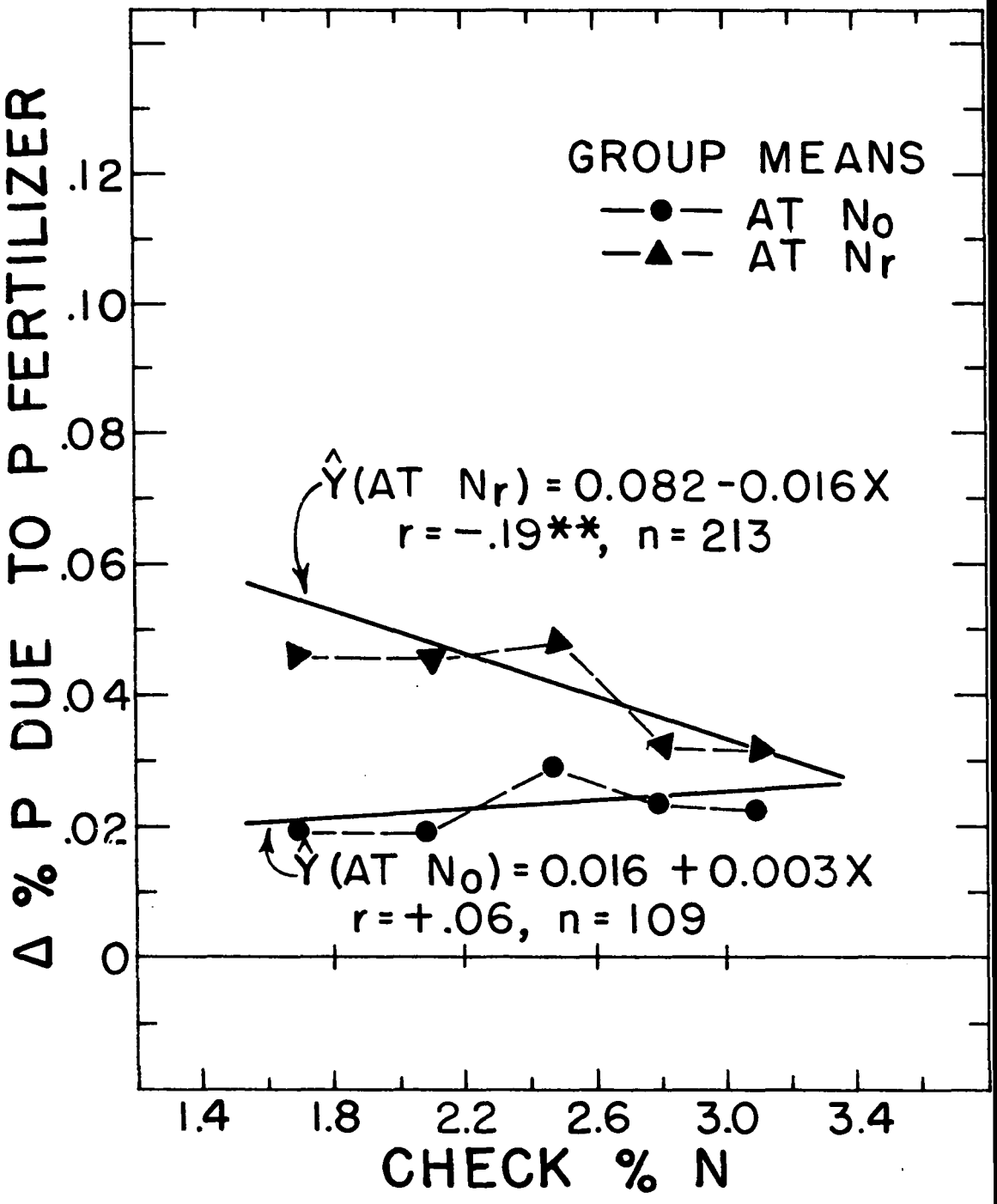

Figure 11. Regressions of the change in percent P in the corn leaf due to P fertilizer, without and with N fertilizer, on the Check percent N in the corn leaf (all P rates)

With N fertilizer, there was a closer relationship between the change in percent P on the percent N in the leaf of the N_rP_0 treatments ($\hat{Y} = 0.149 - 0.0398X$, $r = -0.32^{**}$) than between the change in percent P on the Check percent N ($r = -0.19^{**}$). There was a significant difference between the regression coefficients of these two relationships (Test 7, Table 3). Since the change in percent P of the individual observations was related to either the Check percent N or the percent N of the N_rP_0 treatments in the two relationships, the difference between the two regressions probably is due only to the more narrow range in the percent N observations at N_rP_0 than at N_0P_0.

The regressions of the change in percent P on the percent N in the leaf without and with N also may indicate a three-factor interaction among N and P fertilizers and available soil N on the change in percent P in the leaf due to P fertilizer. If the level of leaf N is due to both soil and fertilizer N, the increase in percent P due to P fertilizer is larger than it is at the same level of leaf N due only to the soil N.

In the preceding relationships, the Check percent N or the percent N in the leaf of the N_rP_0 treatments was used. The relationships would be somewhat different if the percent N in the leaf of the N_0P_r or N_rP_r treatments were used because of the effect of P fertilizer on the percent N in the corn leaf.

The change in the percent N in the leaf due to P fertilizer and the leaf P level were significantly and positively correlated without N fertilizer but were significantly and negatively correlated with N fertilizer (Figure 12). The relationships tended to be curvilinear at the lower leaf P levels. The significant difference between the regression co efficients (Test 1, Table 4) indicates a N fertilizer x leaf

Table 4. Tests of significance between the regression coefficients and adjusted means in the relationships involving the change in the percent N in the corn leaf due to P fertilizer

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Change in the percent N on percent P, at N_0 and N_r (Figure 12)	Within	318	.0203	
		Reg. Coef.	1	.5951	29.3**
		Common	319	.0221	
		Adj. Means	1	.3049	13.8**
2.	Change in the percent N on percent N, at N_0 and N_r (Figure 13)	Within	318	.0212	
		Reg. Coef.	1	.2922	13.7**
		Common	319	.0221	
		Adj. Means	1	.3046	13.7**

P level interaction on the change in the percent N in the lea due to P fertilizer.

The relationships between the change in the percent N due to P fertilizer and the leaf N level, without and with N fertilizer, showed similar, but less marked trends (Figure 13 than the ones between change in leaf N and leaf P level. The significant difference between the regression coefficients

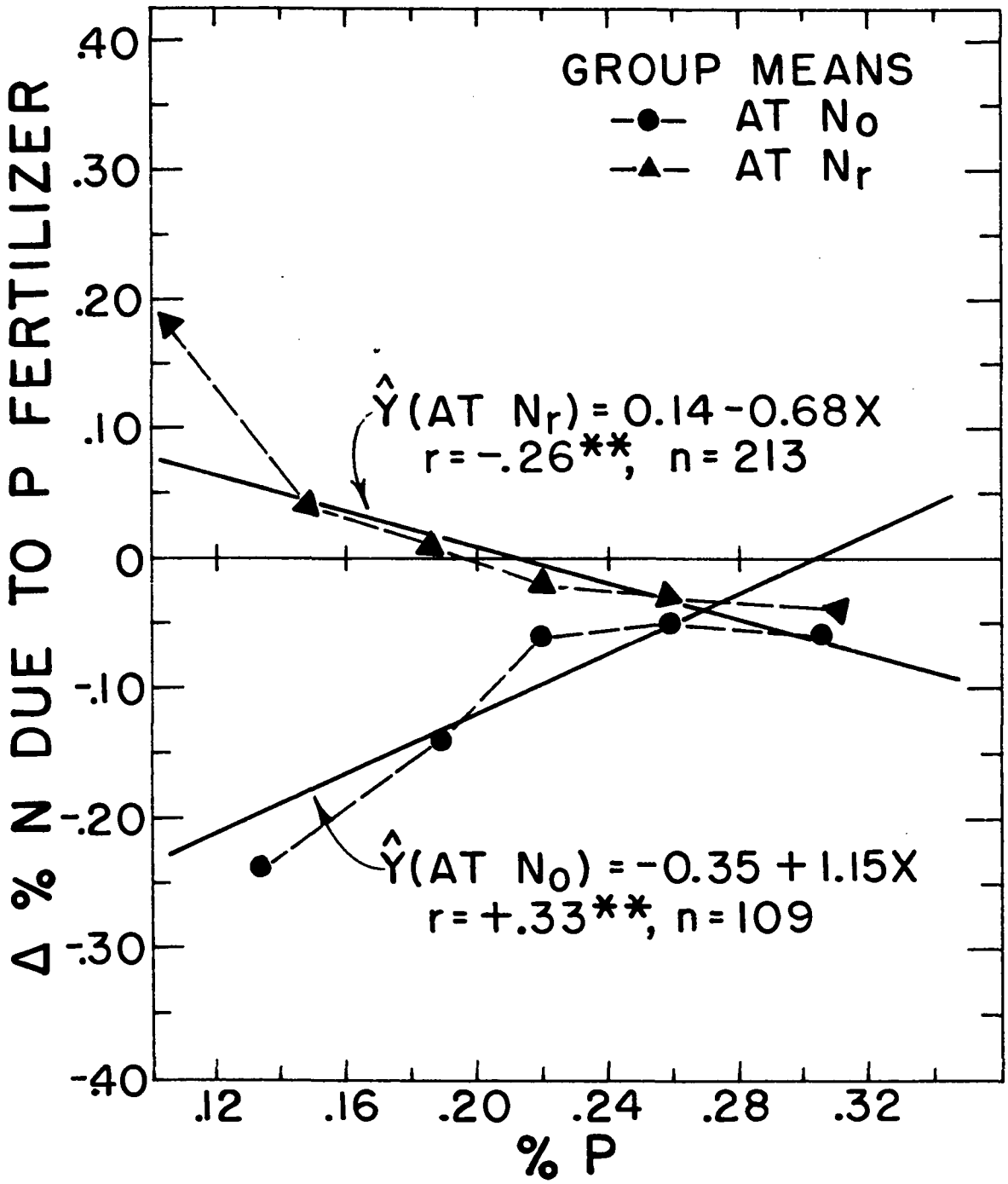

Figure 12. Regressions of the change in percent N in the corn leaf due to P fertilizer, without and with N fertilizer, on the percent P in the corn leaf at N_0P_0 or N_rP_0 (all P rates)

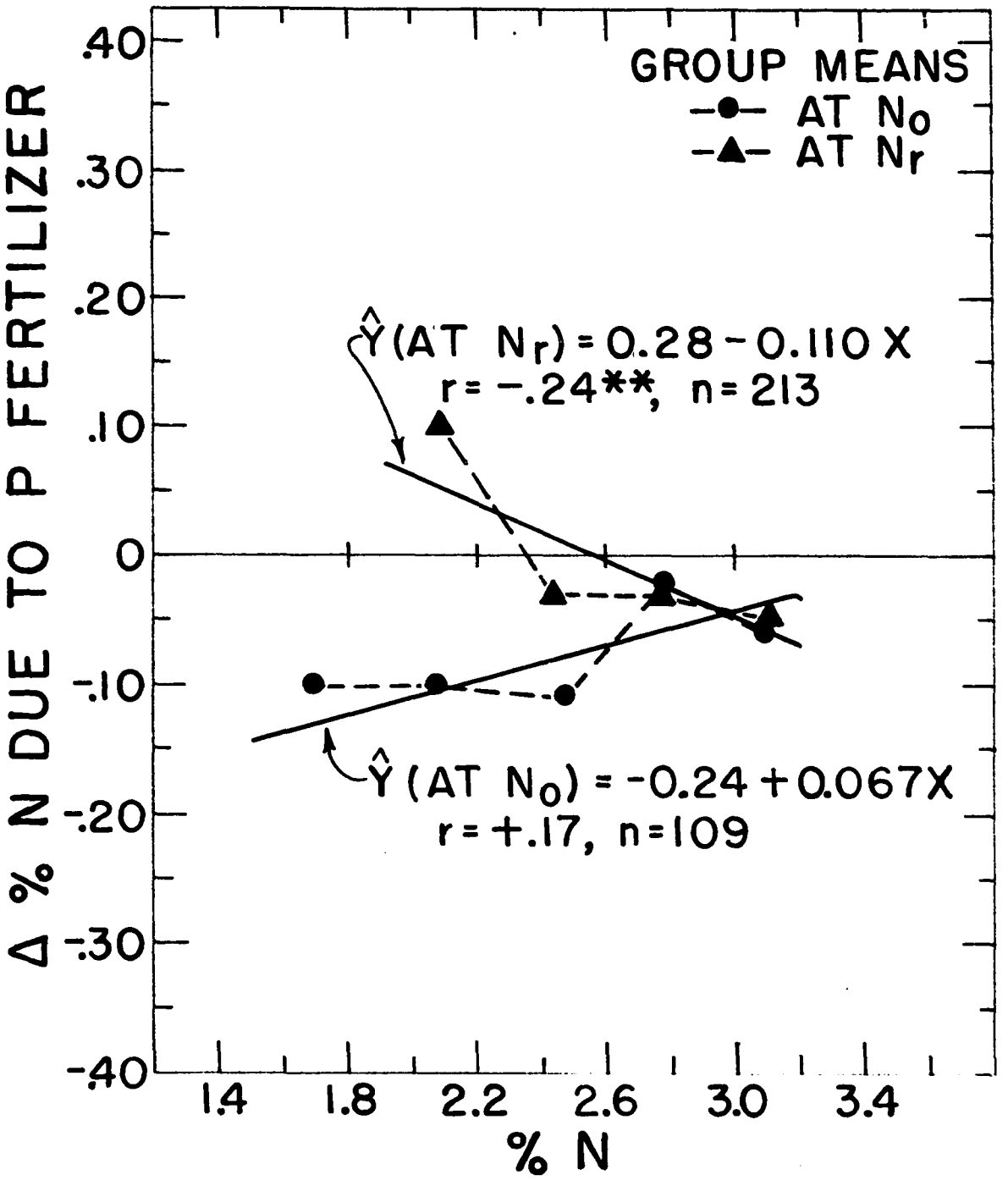

Figure 13. Regressions of the change in percent N in the corn leaf due to P fertilizer, without and with N fertilizer, on the percent N in the corn leaf at N_0P_0 or N_rP_0 (all P rates)

indicates a N fertilizer x leaf N level interaction on the change in leaf N due to P fertilizer (Test 2, Table 4).

Although P fertilizer has affected the leaf N level only to a limited degree, except at the low N and P leaf levels, N fertilizer often has affected the P leaf levels markedly. The NP fertilizer interaction which affected the change in the leaf P level due to P fertilization, as has been shown in the previous discussion, also markedly influenced the effect of N fertilizer on the leaf P level. The change in the percent P in the corn leaf due to N fertilizer was correlated with the leaf P and N levels, soil test P, the yield response due to N, rates of N and P fertilizer and the availability of the subsoil P.

The relationship between the change in the percent P due to N fertilizer and the percent P in the leaf was significant, negative and appeared to be linear without P fertilizer, but it was highly significant and appeared to be curvilinear with P fertilizer (Figure 14). The highly significant difference between the regression coefficients without and with P (Test 1, Table 5) indicates a P fertilizer x leaf P interaction on the change in percent P due to N fertilizer. The difference between the adjusted means shows the presence of a large positive NP fertilizer interaction on this change in the leaf P.

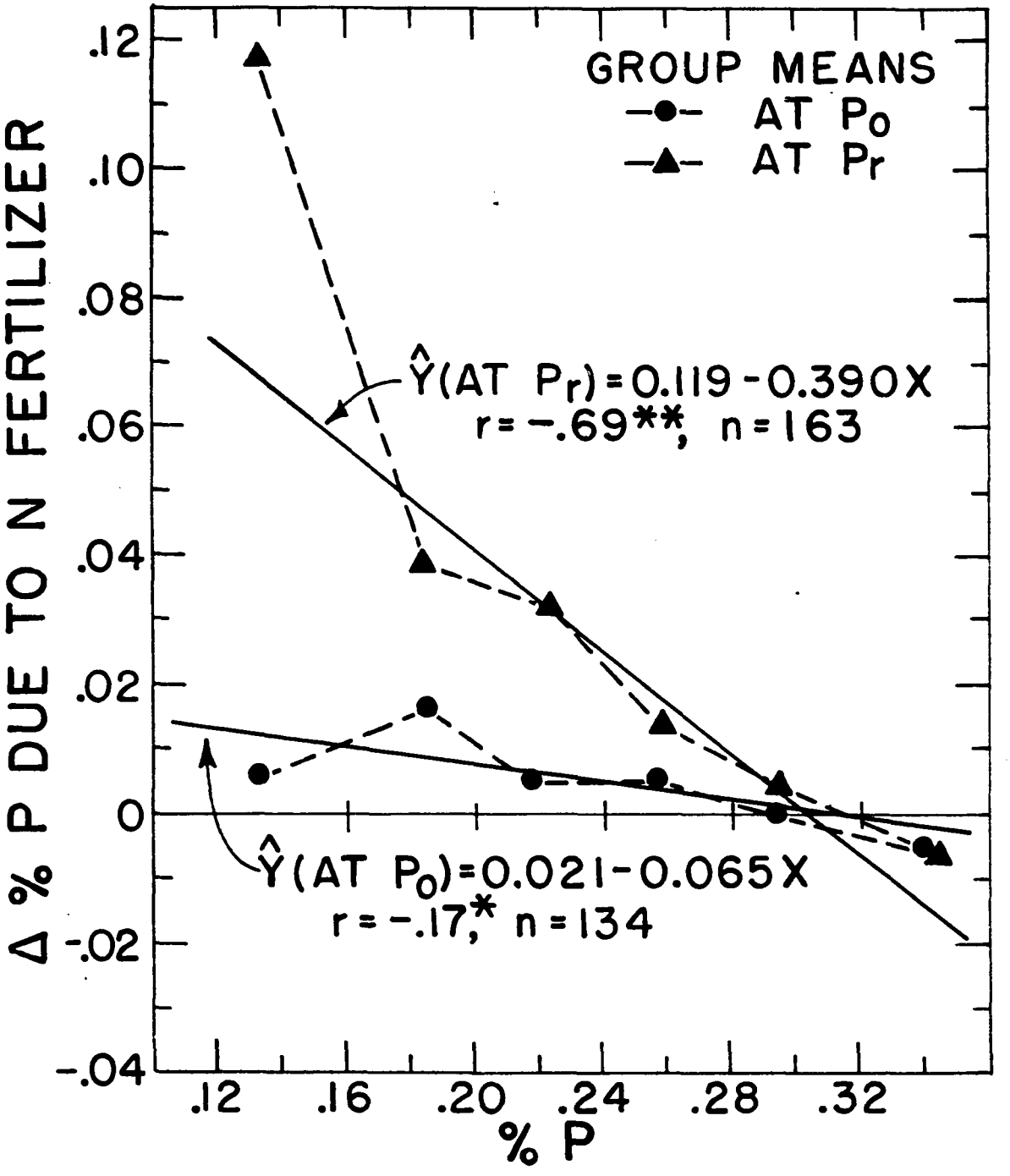

Figure 14. Regressions of the change in percent P in the corn leaf due to N fertilizer, without and with P fertilizer, on the percent P in the corn leaf at N_0P_0 or N_0P_r (all N rates)

Table 5. Tests of significance between the regression coefficients and adjusted means in the relationships involving the change in the percent P in the corn leaf due to N fertilizer

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Change in percent P on the percent P, at P_0 and P_r (Figure 14)	Within	293	.00036	
		Reg. Coef.	1	.01817	51.0**
		Common	294	.00042	
		Adj. Means	1	.02461	59.1**
2.	Change in percent P on the percent N, at P_0 and P_r (Figure 15)	Within	293	.00035	
		Reg. Coef.	1	.00622	17.7**
		Common	294	.00037	
		Adj. Means	1	.01144	30.8**
3.	Change in percent P on soil test P, at P_0 and P_r (Figure 16)	Within	293	.00053	
		Reg. Coef.	1	.00320	6.00*
		Common	294	.00054	
		Adj. Means	1	.01526	28.1**
4.	Change in percent P on yield response to N, at P_0 and P_r (Figure 17)	Within	293	.00027	
		Reg. Coef.	1	.00014	0.52
		Common	294	.00027	
		Adj. Means	1	.00309	11.5**

The change in the percent P due to N fertilizer and the percent N in the corn leaf were significantly and negatively correlated, but the relationship appeared to be linear without P and curvilinear with P fertilizer (Figure 15). The highly significant difference between the regression coefficients without and with P (Test 2, Table 5) indicates a P fertilizer x leaf percent N interaction on the change in percent P due to N fertilizer.

The change in percent P due to N fertilizer had a positive, linear relationship with the soil test P level without

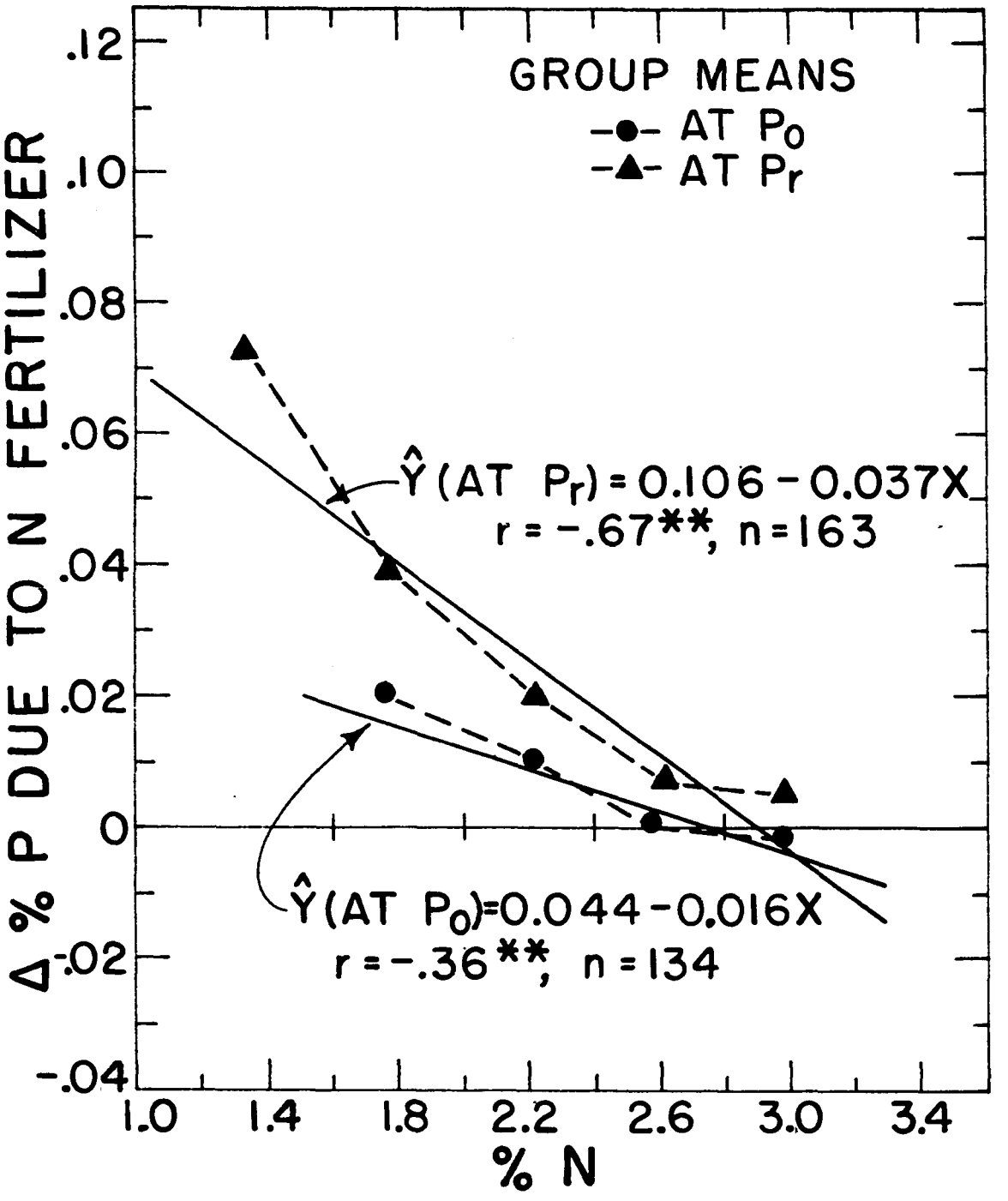

Figure 15. Regressions of the change in percent P in the corn leaf due to N fertilizer, without and with P fertilizer, on the percent N in the corn leaf at N_0P_0 or N_0P_r (all N rates)

P fertilizer but the relationship between the two was not significant with P fertilizer (Figure 16). The significant difference between the regression coefficients (Test 3, Table 5) indicates a P fertilizer x soil test P interaction on the change in the percent P due to N fertilizer. The positive relationship between the change in the percent P due to N fertilizer and soil test P level without P fertilizer was different from the negative one between the change in the percent P and leaf percent P in the absence of P fertilizer, although both the soil test P and the leaf P should indicate the availability of the P in the soil. Since the change in the percent P due to N fertilizer was negatively related to the leaf N level, the difference between the relationships involving soil test P and leaf P may be due to the much higher correlation between the leaf N and P than between the leaf N and soil test P.

The relationships between the change in the percent P due to N fertilizer and the response to N fertilizer, without and with P fertilizer, were highly significant, positive and linear (Figure 17). The difference between the regression coefficients was not significant but the difference between the adjusted means was highly significant (Test 4, Table 5). The high correlation between the change in the leaf P due to N fertilizer and the yield response to N probably reflects the effect of the N and P leaf levels on the change in the leaf

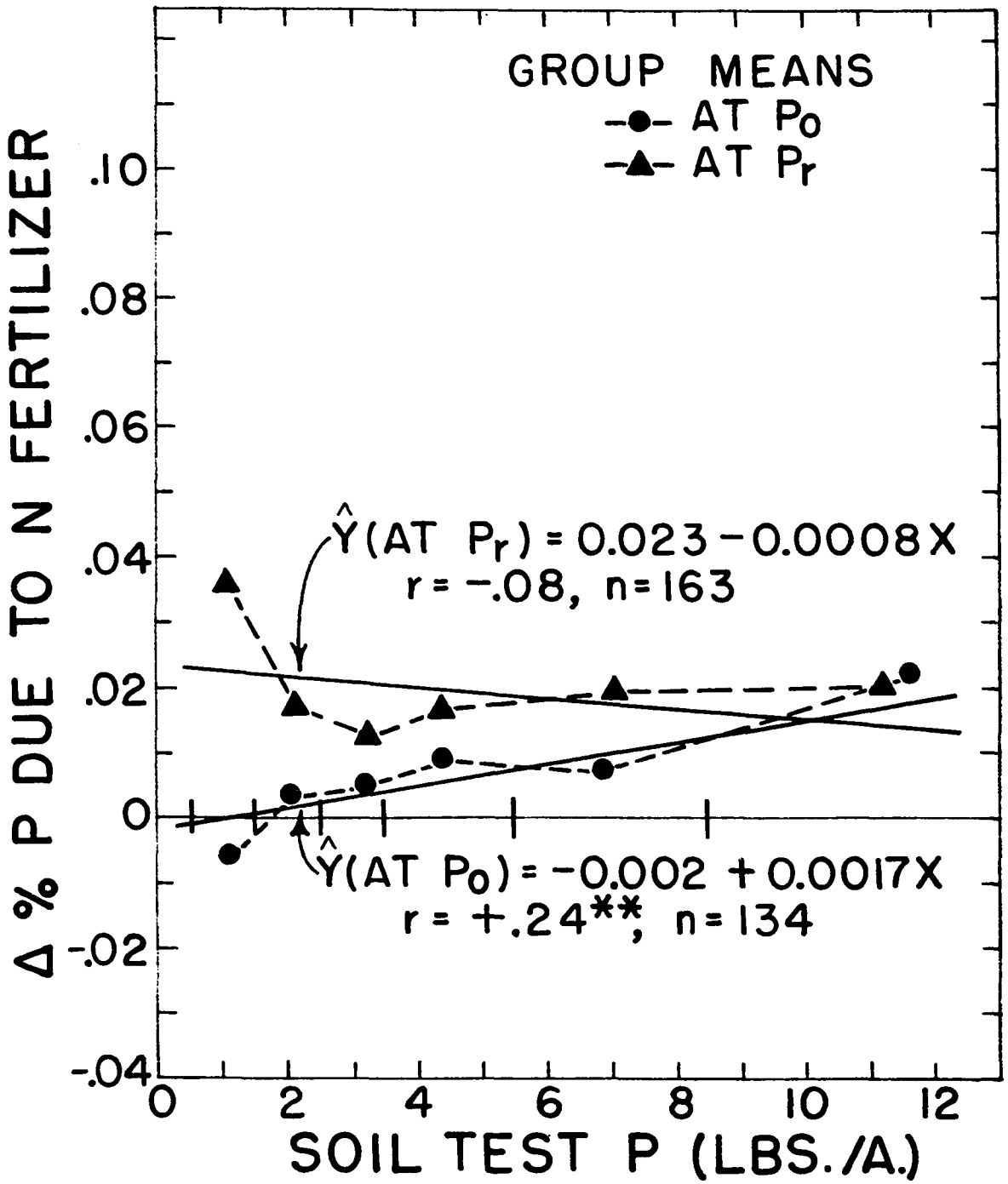

Figure 16. Regressions of the change in percent P in the corn leaf due to N fertilizer, without and with P fertilizer, on the soil test P in the plow-layer (all N rates)

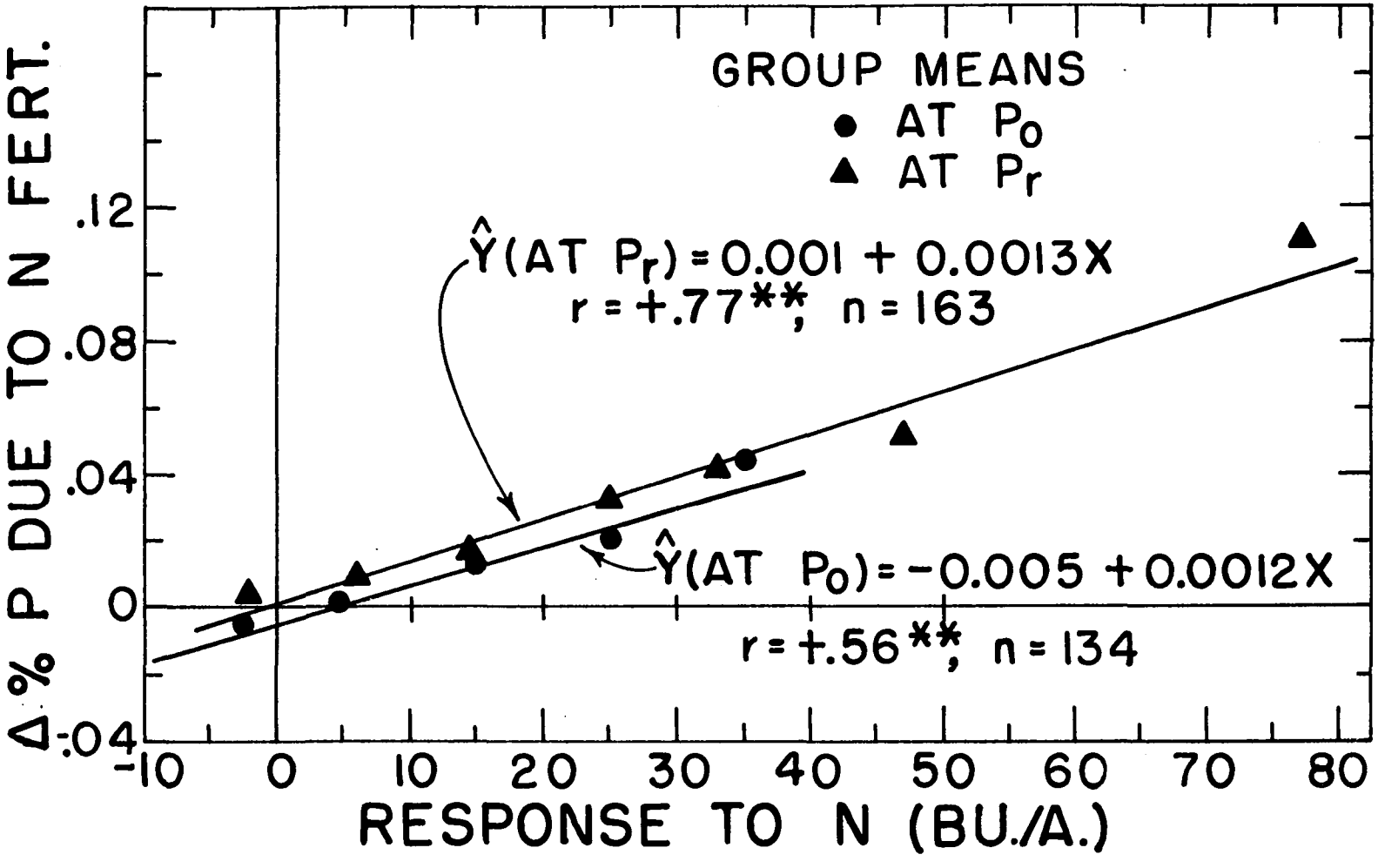

Figure 17. Regressions of the change in percent P in the corn leaf due to N fertilizer, without and with P fertilizer, on the corn yield response to N fertilizer (all N rates)

P due to N fertilizer plus the positive correlation between the N and P levels in the leaf. The large yield responses to N occur at a low level of N availability in the soil as shown by a low N level in the leaf. A low level of leaf P is also associated with a low leaf N level. The increase in the percent P due to N fertilizer is larger at both of these conditions, particularly in the presence of P fertilizer. In the absence of P fertilizer, the responses to N fertilizer and the change in percent P due to N often are limited at the lower N and P leaf levels.

The change in the percent P due to N fertilizer appeared to be a curvilinear function of the rate of N fertilizer, either without or with P fertilizer. The rate of P fertilizer also influenced the change in percent P from N fertilizer. These results averaged over all observations are given in Table 6.

Although the regressions showed the average change in the percent P due to N fertilizer, the individual observations showed wide variations. The frequency distributions of these changes in the percent P due to N fertilizer without and with P fertilizer are shown in Table 7. The unadjusted means of the change in percent P due to N fertilizer without and with P fertilizer were 0.005 and 0.020% P, respectively. The unadjusted means of these distributions as well as the adjusted means in the various relationships shown in Table 5 were sig-

Table 6. Change in the percent P due to N fertilizer without and with P fertilizer as affected by rates of N and P fertilizer

N rate	Change in the percent P due to N fertilizer At P_0		At P_r		At P_{40}		At P_{80}	
(lbs./A.)	n[a]	Mean	n[a]	Mean	n[a]	Mean	n[a]	Mean
40	40	0.005	57	0.011	29	0.009	28	0.013
60	41	.009	42	.017				
80	29	.007	42	.025	20	.017	22	.032
120	12	.002	12	.017				
160	3	-.005	4	.068				
180	7	-.009	4	.025				

[a]n = number of observations.

nificantly different at the 1% level. These distributions show that decreases, no changes or increases may occur, depending upon the several factors discussed previously. They also explain the variations in the effect of N fertilizer on the leaf P level reported in the literature (3, 4, 14, 16,

Table 7. Frequency distribution of the changes in the percent P due to N fertilizer without and with P fertilizer (all N and P rates)

Class interval of the change in percent P	Without P Frequency	Without P Percentage frequency	With P Frequency	With P Percentage frequency
<-0.030	1	0.7	2	1.2
-0.030 to -0.011	22	16.4	8	4.9
-0.010 to 0.010	70	52.2	61	37.4
0.011 to 0.030	26	19.4	53	32.5
0.031 to 0.050	12	9.0	22	13.5
0.051 to 0.070	3	2.2	10	6.1
>0.070	0	0.0	7	4.3

27, 41, 44, 65, 83, 91) where, in almost all cases, only one to a few experiments were conducted.

The effect of N fertilizer on the change in the percent P in the corn leaf is a complicating factor in the interpretation of leaf composition. The addition of P or K fertilizer usually has little effect or decreases the level of the other nutrients depending upon the level of the other nutrients. The wide variability in the effect of N on the leaf P must be predicted before the leaf analysis method can be used with any precision. The marked NP interaction indicates that this N effect on leaf P is related primarily to the P availability in the soil although interactions among N and P fertilizer and the N and P availability in the soil appear to be contributing factors.

The effect of N fertilizer on the change in the leaf P was different among the various soil types or association areas in Iowa (Table 8). The experiments with leaf levels greater than 0.29% P or 2.8% N (near the critical levels) in the N_0P_0 or N_0P_r treatments were not included since little change in the percent P due to N fertilizer occurred at these high leaf levels. On most of the soils in the Clarion-Webster, Marcus-Primghar-Sac, Galva-Primghar-Sac and Moody Soil Association Areas and on the Ida soil, the N fertilizer had no effect or decreased the percent P in the corn leaf without P fertilizer but increased the leaf P with P ferti-

Table 8. Frequency distribution of the effects of N fertilizer, without and with P fertilizer, on the change in the percent P in the corn leaf in the experiments on the various Iowa soils (average effect over all N and P rates)

Soils	Change in percent P, without P				Change in percent P, with P			
	Number of fields			% of fields	Number of fields			% of fields
	<-.010	±.010	>.010	>.010	<-.010	±.010	>.010	>.010
Tama, Muscatine	1	1	5		0	1	6	
Mahaska, Taintor	0	2	2		0	0	4	
Grundy, Haig	1	0	2		0	1	1	
Total	2	3	9	64	0	2	11	85
Fayette, Downs	1	1	4		0	0	5	
Carrington, Floyd, Clyde	1	1	6		0	0	7	
Total	2	2	10	71	0	0	12	100
Clarion	2	1	1		0	0	4	
Nicollet	0	1	3		0	0	4	
Webster	1	3	0		0	1	2	
Total	3	5	4	33	0	1	10	91
Galva, Sac	2	2	4		0	1	6	
Primghar, Marcus	1	3	2		0	1	5	
Moody	0	2	2		0	0	3	
Total	3	7	8	44	0	2	14	88
Marshall, Sharpsburg	0	1	2	67	0	0	3	100
Mo. bottomland	0	1	2	67	0	0	3	100
Ida	1	1	0	0	0	0	2	100
Weller, Belinda	0	1	1	50	0	0	2	100

lizer. Large positive NP fertilizer interactions on yield and leaf P have occurred most often on these soils. On most of the other soils, N fertilizer increased the leaf P when the leaf N and P levels were below the approximate critical levels. In these soils NP fertilizer interactions on yield and percent P have been non-existent, small and positive or occasionally negative.

Differences in the P availability in the subsoil may account for the differences in behavior between the two broad groups of soils. The soil types or areas where the N fertilizer decreases or has no effect on the leaf P have very low amounts of available P in the subsoil. Most of the other soils have higher amounts of available P in the subsoil except the soils in the Carrington-Clyde Soil Association Area. These soils apparently have a low level of P availability in the subsoil and also a low level in the surface soil as indicated by the chemical P soil tests. However, the plant available P in these soils is often high as indicated by low responses to P fertilizer and high percent P in the corn leaf. Another factor must be contributing to the high availability of the P in these soils. The use of more manure and rotations with higher percentages of legumes on these soils than in other areas may increase the amount of P released from organic forms.

The NP fertilizer interaction has been shown in the previous discussion to have a marked effect on the change in leaf

P due to N and P fertilization. Its components, where more than two levels of N and P fertilizer were used, were estimated to determine whether components other than the linear x linear term were needed in the regression equation.

In each individual experiment which had two or more degrees of freedom associated with the NP interaction, the mean squares of each component on the percent N and percent P in the leaf were determined. These are given in Table 9. Since analysis of variance was not calculated for the individual experiments, an error variance (s^2) for testing the approximate significance of the components was estimated in each experiment from the relationship, $C = s/\bar{x}$, assuming an average coefficient of variation (C) of 8% and using the mean ($\bar{x}$) of the percent N and percent P in each experiment. Testing the significance of the NP interaction components at approximately the 10% significance level, there were no more fertilizer interactions on the percent N in the leaf than would occur by chance. The number of significant linear x linear NP interactions on the percent P was greater than would occur by chance but the number of linear x quadratic, quadratic x linear or quadratic x quadratic NP interactions was no more than would occur by chance. From these approximations, the linear x linear NP interaction term appears to be the only necessary term in the regression equations involving the fertilizer interaction on leaf P.

Table 9. Analyses of variance of the components of the NP interaction on the percent N and percent P in the corn leaf in the experiments having more than two levels of N or P fertilizer

Expt. no.[b]	Percent N[a]				Percent P[a]			
	N_LP_L	N_LP_Q	N_QP_L	N_QP_Q	N_LP_L	N_LP_Q	N_QP_L	N_QP_Q
16	.00	.06	.01	.00	.0001	.0002	.0000	.0000
17	.00	.00	.00	.00	.0001	.0000	.0001	.0001
19	.10	.01	--	--	.0001	.0014	--	--
23	.01	.02	.00	.00	.0003	.0001	.0007	.0000
24	.01	.01	.00	.02	.0007	.0000	.0001	.0001
25	.27[c]	.05	.03	.00	.0028[c]	.0005	.0003	.0000
26	1.11[c]	.10[c]	.05	.04	.0120[c]	.0001	.0016[c]	.0034[c]
35	.00	.00	.02	.02	.0002	.0004	.0001	.0000
36	.06	.02	.01	.01	.0001	.0000	.0000	.0004
37	.00	.00	.01	.02	.0001	.0003	.0000	.0000
38-P	.03	.01	--	--	.0009	.0001	--	--
-D	.00	.00	--	--	.0000	.0003	--	--
39-P	.00	.01	--	--	.0000	.0001	--	--
-D	.01	.00	--	--	.0000	.0001	--	--
40-P	.00	.01	.07	.00	.0000	.0001	.0000	.0001
D	.03	.02	.03	.01	.0006	.0001	.0004	.0003
42-P	.00	.13	--	--	.0001	.0008	--	--
D	.02	.01	--	--	.0000	.0010	--	--
47	.01	--	.03	--	.0065[c]	--	.0000	--

[a]All values are mean squares with 1 d.f. for the interaction component listed. N_LP_L, N_LP_Q, N_QP_L and N_QP_Q refer to the linear x linear, linear x quadratic, quadratic x linear and quadratic x quadratic components, respectively, of the NP interaction.

[b]Expt. no. = experiment number; P = broadcast and plowed under and D = broadcast and disked in.

[c]Significant at approximately the 10% level. The errors (s^2) were calculated from the relationship, $C = s/\bar{x}$, assuming an average coefficient of variation (C) of 8% and using the mean ($\bar{x}$) of the percent N and P in each experiment. The error variances in each experiment are not given but averaged 0.043 and 0.00042 for the percent N and percent P, respectively.

Table 9. (Continued)

Expt. no.[b]	Percent N[a]				Percent P[a]			
	N_LP_L	N_LP_Q	N_QP_L	N_QP_Q	N_LP_L	N_LP_Q	N_QP_L	N_QP_Q
50	.10	--	.00	--	.0015[c]	--	.0001	--
51	.05	--	.01	--	.0001	--	.0001	--
55-P	.01	--	.02	--	.0004	--	.0000	--
-D	.06	--	.00	--	.0024[c]	--	.0001	--
56-P	.01	--	.00	--	.0000	--	.0003	--
-D	.01	--	.02	--	.0001	--	.0003	--
57-P	.00	--	.00	--	.0006	--	.0007	--
-D	.01	--	.00	--	.0000	--	.0001	--
58-P	.08	--	.01	--	.0015[c]	--	.0002	--
-D	.03	--	.01	--	.0009[c]	--	.0000	--
71	.02	--	.00	--	.0000	--	.0001	--
72	.05	--	.00	--	.0027[c]	--	.0003	--
73	.01	--	.03	--	.0005	--	.0011	--
77	.04	.00	.02	.00	.0001	.0000	.0000	.0007
78	.01	.04	.00	.09[c]	.0030[c]	.0002	.0004	.0015[c]
79	.02	.01	.14[c]	.10	.0000	.0000	.0013	.0001
107	.01	.11[c]	.13[c]	.01	.0017[c]	.0005	.0011	.0000
109	.00	--	.00		.0000	--	.0000	--
110	.00	--	.00	--	.0000	--	.0001	--
111	.00	--	.00	--	.0000	--	.0001	--
112	.00	--	.05	--	.0000	--	.0005	--
113	.00	--	.00	--	.0001	--	.0003	--
114	.00	--	.00	--	.0001	--	.0000	--
Number	42	22	35	15	42	22	35	16
Number significant	2	2	2	1	10	0	1	2

There was no relationship between the change in percent P in the leaf due to P fertilizer and stand level at all P rates and with N fertilizer ($r = 0.03$, $n = 213$). Multiple regression will be necessary to determine the relationship between the two, if any exists.

In the experiments comparing time and method of P fertilizer application, the change in the percent P was larger from fall plowed-under than from spring disked-in application (Table 10). This difference probably was due to the depth of placement rather than due to time of application. The difference in the change in the percent P due to methods of application appears to be correlated with the difference in yield responses.

Table 10. Effect of method of P application on the change in the percent P in the corn leaf and yield response to P fertilizer (over all P rates)

Method[a]	Locations	Comparisons	N level	Mean P rate	Percent P at P_0	Change in percent P	Mean response to P (bu./A.)
BPU	9	13	N_0	66	0.205	0.044	15.4
BDI	9	13	N_0	66	.205	.027	12.0
BPU	16	33	N_r	63	.225	.055	20.4
BDI	16	33	N_r	63	.224	.041	16.3

[a]BPU = broadcast and plowed under; BDI = broadcast and disked in.

In summary, the hypothesis to be tested is that the change in percent P in the corn leaf due to N and P fertilization may be expressed as a function of the following factors: (1) percent P without fertilizer (curvilinear), (2) soil test P level (curvilinear), (3) percent N without fertilizer

(curvilinear), (4) N fertilizer level (curvilinear), (5) P fertilizer level (curvilinear), (6) NP fertilizer interaction, (7) N fertilizer x percent N interaction, (8) N fertilizer x percent P interaction, (9) P fertilizer x percent N interaction, (10) P fertilizer x percent P interaction, (11) N fertilizer x soil test P interaction, (12) P fertilizer x soil test P interaction, (13) percent N x percent P interaction, (14) percent N x soil test P interaction, (15) subsoil test P, (16) stand level and (17) method of application.

2. Percent P

The percent P in the corn leaf at any N and P fertilizer treatment may be estimated from the factors affecting the change in the percent P if the percent P in the leaf without fertilizer is known. If the Check percent P is not known, the percent P in the leaf then may be estimated from a regression equation of the percent P on other factors.

The factors investigated affecting the percent P in the corn leaf were N and P fertilizers, NP fertilizer interaction, P availability in the soil (surface and subsoil P tests), N availability in the soil (Check percent N), N and P fertilizer interactions with the P soil test and Check percent N, the percent N in the leaf of the same fertilizer treatment, stand level and method of P application. Since many of these factors were discussed in respect to the change in the percent P and

whose effects would be similar in estimating the percent P in the corn leaf, they will not be discussed further. The relationships to be discussed in this section will be those between the percent P in the leaf and the soil test P level in the surface soil and subsoil, Check percent N, percent N in the leaf of the same fertilizer treatment, stand level and some of the fertilizer interactions involved.

The percent P in the corn leaf and soil test P in the plow-layer, without and with N, were positively and significantly correlated and the relationships were curvilinear at the low soil test P levels (Figure 18). The regression coefficients were significantly different but the adjusted means were not different (Test 1, Table 11). The difference between

Table 11. Tests of significance between or among the regression coefficients and adjusted means in the relationships involving the percent P in the corn leaf

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Percent P on the soil test P, at N_0 and N_r (Figure 18)	Within	227	.00215	
		Reg. Coef.	1	.00878	4.08*
		Common	228	.00218	
		Adj. Means	1	.00021	0.09
2.	Percent P on the soil test P in the subsoil, at N_0 and N_r	Within	227	.00227	
		Reg. Coef.	1	.00001	0.00
		Common	228	.00226	
		Adj. Means	1	.00013	0.06
3.	Percent P on the percent N, at N_0P_0, N_rP_0, N_0P_r, and N_rP_r (Figure 19)	Within	560	.00137	
		Reg. Coef.	3	.00341	2.48*
		Common	563	.00139	
		Adj. Means	3	.05344	38.5**

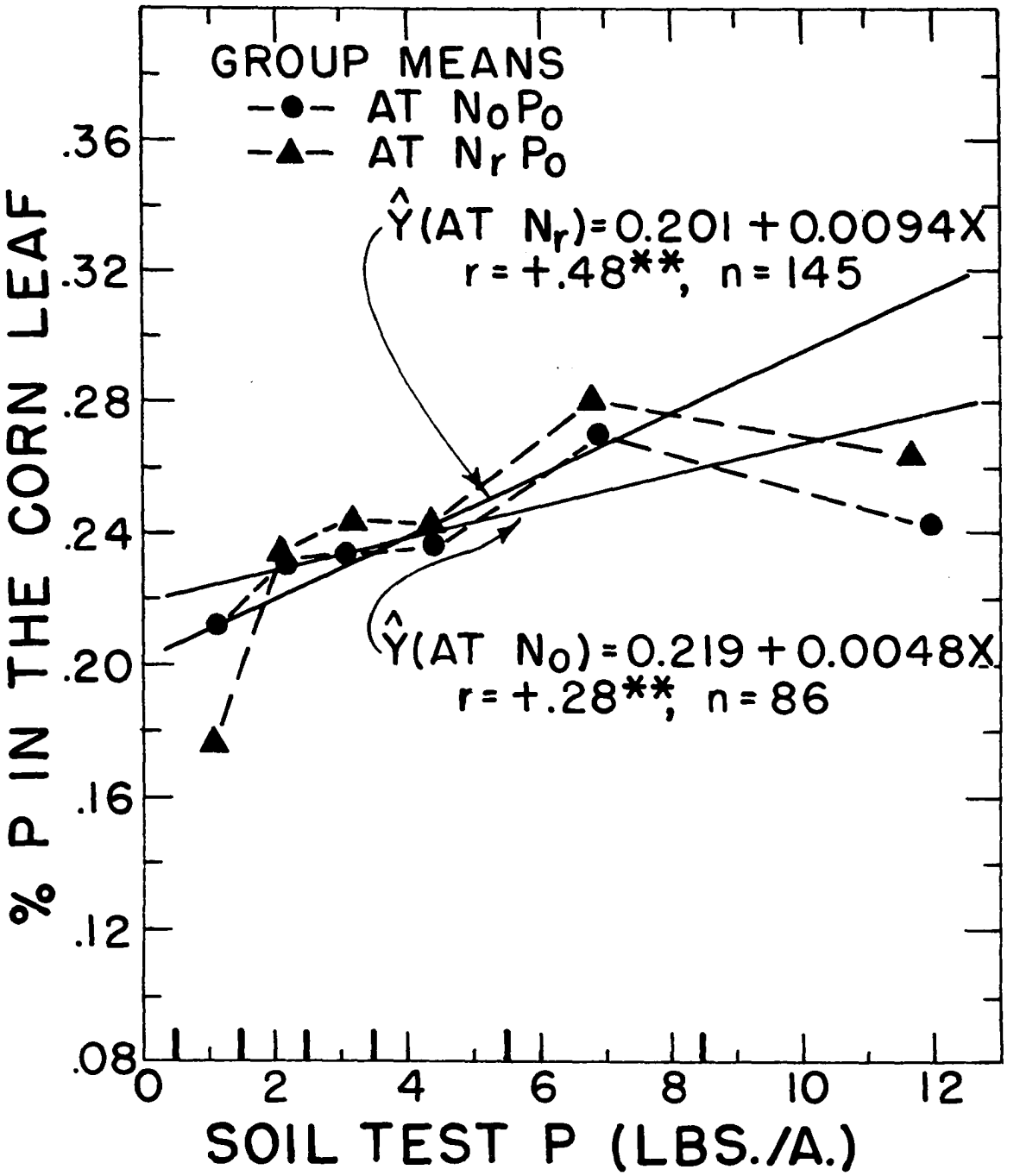

Figure 18. Regressions of the percent P in the corn leaf, without and with N fertilizer, on the soil test P in the plow-layer

the regression coefficients indicates a N fertilizer x soil test P interaction on the percent P in the leaf.

The relationships between the percent P in the leaf and the soil test P in the subsoil, without and with N, were positive and highly significant (r = 0.39** and 0.35**, respectively) and were curvilinear at the low subsoil test P levels (Table 12). The regression coefficients and adjusted means were not different without and with N fertilizer (Test 2,

Table 12. Effect of the soil test P in the subsoil on the percent P in the corn leaf, without and with N fertilizer

Range of the subsoil test P values[b]	At N_0P_0			At N_rP_0		
	n[a]	Mean subsoil test P	Mean percent P	n[a]	Mean subsoil test P	Mean percent P
0.5 to 0.9	31	0.7	.216	57	0.7	.208
1.0 to 1.5	18	1.2	.240	38	1.2	.254
1.6 to 5.5	12	3.3	.256	20	3.5	.253
5.6 to 10.0	15	9.1	.247	16	9.1	.266
10.1 to 18.0	0	--	--	0	--	--
18.1 to 30.0	10	28.4	.291	14	29.7	.286

[a]n = number of observations within each sub-range.

[b]Values are pounds of P per acre 6 2/3 inches.

Table 11). The degree of correlation may be somewhat misleading, however, because of the unequal distribution and extended range of the values.

The correlations between the percent P and the percent N in the leaf at the N_0P_0, N_rP_0, N_0P_r and N_rP_r treatments

were positive and highly significant (Figure 19). The relationships appeared to be mostly linear except for some curvature near the critical N and P levels. The differences among the regression coefficients of the four treatments and among the adjusted means were significant and highly significant, respectively (Test 3, Table 11). As is shown in Figure 19, the regression coefficient of the N_rP_0 treatment differed significantly from the rest but no significant difference existed among the other regression coefficients. These relationships show that the ratio of the percent P to the percent N in the corn leaf is not constant but varies with initial leaf N level and fertilizer treatment.

There was no significant relationship between the percent P in the corn leaf and stand level, either without or with N and P fertilizer (Table 13). The correlation coefficients

Table 13. The effect of stand level on the percent N and percent P in the corn leaf, without and with N and P fertilizer

Range of stand level[a]	At N_0P_0				At N_rP_r			
	n[b]	Mean stand	Mean percent N	Mean percent P	n[b]	Mean stand	Mean percent N	Mean percent P
<10.1	7	9.2	2.57	.231	18	9.2	2.55	.266
10.1 to 12.0	27	11.2	2.40	.236	72	11.2	2.72	.275
12.1 to 14.0	34	13.1	2.56	.249	93	13.0	2.74	.288
14.1 to 16.0	10	14.5	2.34	.239	24	14.6	2.62	.256
>16.0	8	18.0	2.29	.235	21	17.6	2.54	.269

[a]Stand level given in thousands of stalks per acre.

[b]n = number of observations.

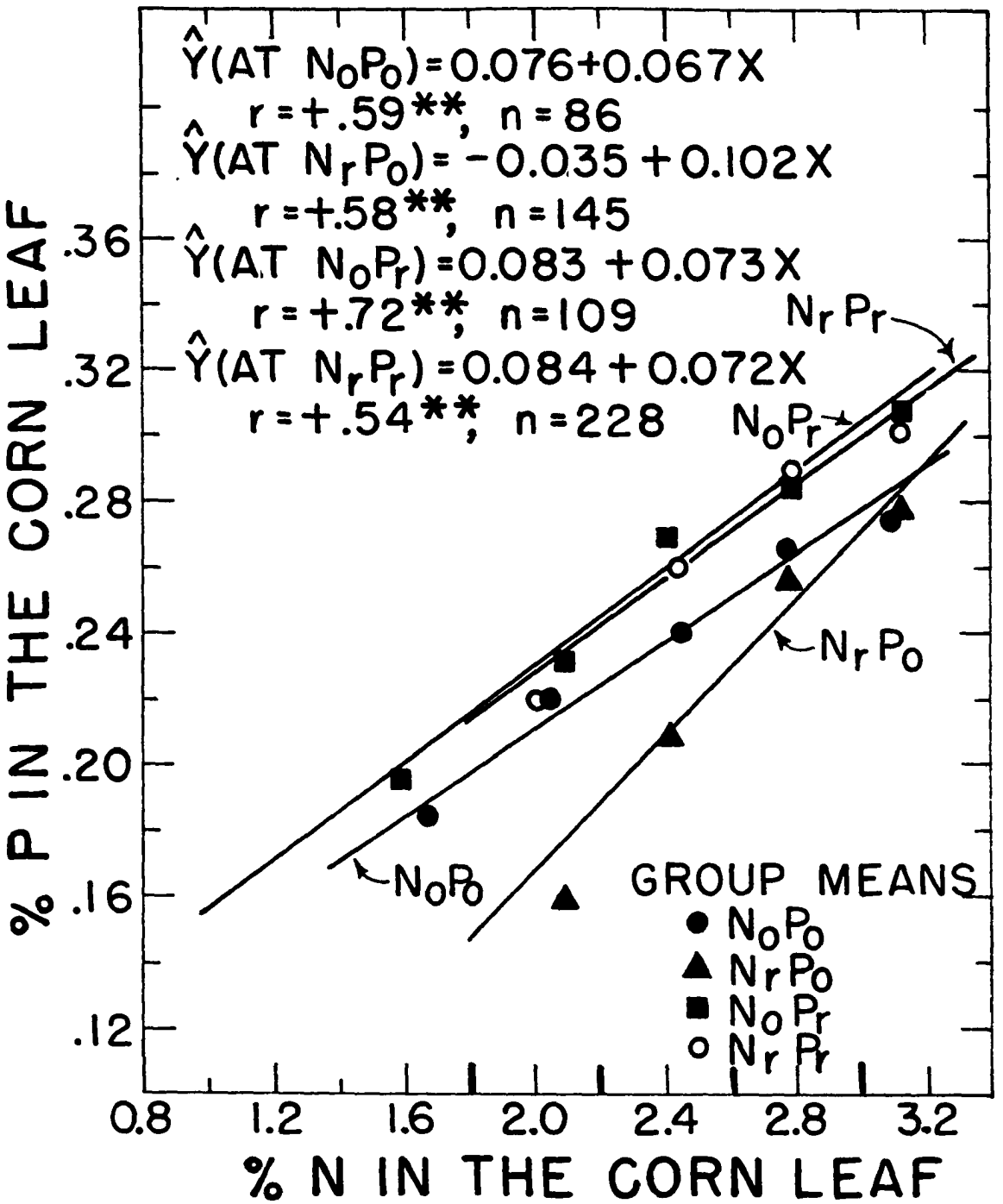

Figure 19. Regressions of the percent P in the corn leaf on the percent N in the corn leaf at the N_0P_0, N_rP_0, N_0P_r and N_rP_r fertilizer treatments

between percent P and stand level at N_0P_0 and N_rP_r were 0.06 and -0.01, respectively. Since the percent P is highly correlated with the percent N in the leaf, the relationship between the percent N and stand level was also determined (Table 13). The percent N and stand level was not significantly related either without or with N and P fertilizer (r = -0.11 at both N_0P_0 and N_rP_r) although the linear trend was negative.

In summary, the hypothesis to be tested is that the percent P in the corn leaf at any N and P fertilizer treatment may be expressed as a function of the following factors: (1) soil test P level (curvilinear), (2) Check percent N (curvilinear), (3) percent N of the corresponding treatment (curvilinear), (4) N fertilizer level (curvilinear), (5) P fertilizer level (curvilinear), (6) NP fertilizer interaction, (7) N fertilizer x soil test P interaction, (8) P fertilizer x soil test P interaction, (9) N fertilizer x Check percent N interaction, (10) P fertilizer x Check percent N interaction, (11) subsoil test P level and (12) stand level.

3. <u>Change in yield</u>

In the third phase of this study, the factors that might be used to predict the change in yield due to N and P fertilization were investigated. These factors were the availability of the N and P in the soil, N and P fertilizer rates,

NP fertilizer interaction, interactions of N and P fertilizers with the N and P availabilities in the soil, stand level, method of fertilizer application and the initial yield level. In order to study the various interactions, the relationships of the responses to N or P fertilizer and the various factors were determined in the presence and absence of the other nutrient.

As previously shown in Figure 7, there was a high, positive correlation between the yield response to P fertilizer and the change in the percent P in the corn leaf due to P fertilization. The factors that influenced the change in percent P and which were discussed before should also affect the yield response to P fertilizer in a similar manner.

All of the factors which influence the change in the percent N in the corn leaf due to fertilization were not investigated. The relationships between the yield response to N and the change in the percent N due to N fertilization, without and with P fertilizer, were highly significant, positive and tended to be linear (Figure 20). Therefore, the factors which affect the response to N should also affect the percent N in the leaf because of the high correlation between the two. The highly significant differences between the regression coefficients and the adjusted means without and with P fertilizer (Test 1, Table 14) show a marked NP interaction

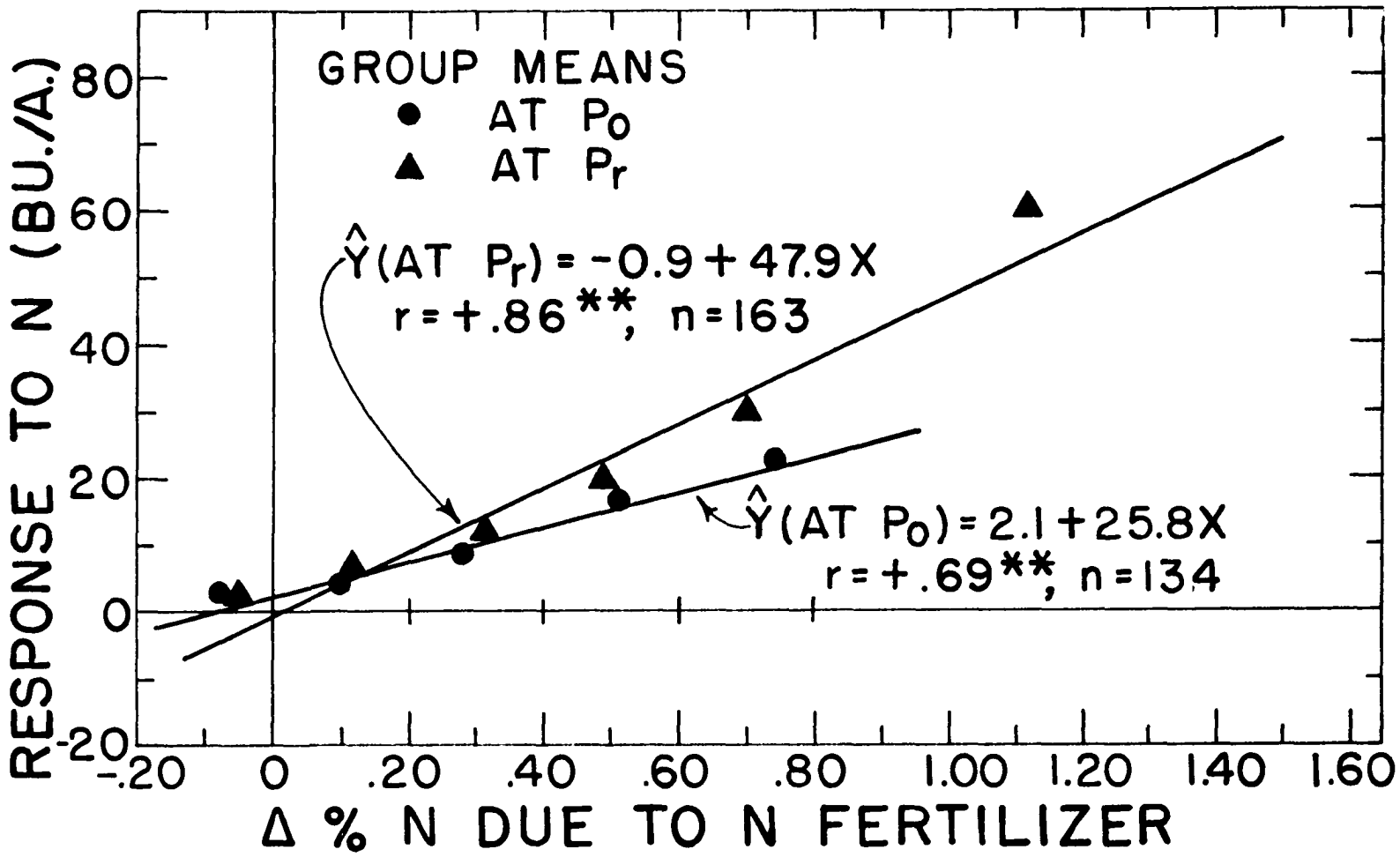

Figure 20. Regressions of the corn yield response to N fertilizer, without and with P fertilizer, on the change in percent N in the corn leaf due to N fertilizer (all N rates)

Table 14. Tests of significance between or among the regression coefficients and adjusted means in the relationships involving yield responses to N and P fertilizer

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Response to N on the change in percent N due to N fertilizer, at P_0 and P_r (Figure 20)	Within	293	57.0	
		Reg. Coef.	1	2395.5	42.0**
		Common	294	64.9	
		Adj. Means	1	828.7	12.7**
2.	Response to P on the Check percent P, at N_0 and N_r (Figure 21)	Within	318	137.6	
		Reg. Coef.	1	3825.7	27.8**
		Common	319	149.2	
		Adj. Means	1	4479.7	30.0**
3.	Response to P on the Check percent P and the percent P of the N_rP_0 treatment, at N_r	Within	422	147.2	
		Reg. Coef.	1	134.6	0.91
		Common	423	147.2	
		Adj. Means	1	89.4	0.61
4.	Response to rates of P on the percent P of the N_rP_0 treatment, at N_r (Figure 22)	Within	205	88.8	
		Reg. Coef.	3	2508.0	28.2**
		Common	208	123.7	
		Adj. Means	3	668.2	5.4**
5.	Response to P on the soil test P, at N_0 and N_r (Figure 23)	Within	318	166.7	
		Reg. Coef.	1	2857.6	17.1**
		Common	319	175.1	
		Adj. Means	1	4255.4	24.3**
6.	Response to rates of P on the soil test P, at N_r (Figure 24)	Within	205	167.7	
		Reg. Coef.	3	1875.2	11.2**
		Common	208	192.3	
		Adj. Means	3	1169.5	6.1**
7.	Response to P of two soil groups on the soil test P, at N_r (Figure 25)	Within	208	161.5	
		Reg. Coef.	1	4228.2	26.2**
		Common	209	180.9	
		Adj. Means	1	5610.6	31.0**

on the regression of the response to N on the change in the leaf N due to N fertilizer.

In order to determine the effect of the P availability in the soil on the change in yield due to fertilization, the yield responses to N and P were correlated with both the percent P in the corn leaf and the soil test P.

The yield response to P and the Check percent P in the leaf were significantly and negatively correlated and the relationship appeared to be curvilinear in the presence of N fertilizer (Figure 21). The correlation was much higher with N than without N fertilizer. The highly significant difference between the regression coefficients without and with N fertilizer indicates a N fertilizer x Check percent P interaction on the response to P (Test 2, Table 14). The highly significant difference between the adjusted means shows the NP fertilizer interaction on the response to P.

With N fertilizer, the percent P in the leaf of the N_rP_0 treatment also may be used to estimate the P availability in the soil. The relationship between the response to P with N fertilizer and the percent P in the N_rP_0 treatment was similar to the one between the response to P fertilizer and the Check percent P (Test 3, Table 14). The correlation coefficient was somewhat higher between the response to P and the percent P in the N_rP_0 treatment ($r = -0.72^{**}$) than between the response to P and the Check percent P ($r = -0.64^{**}$). This difference

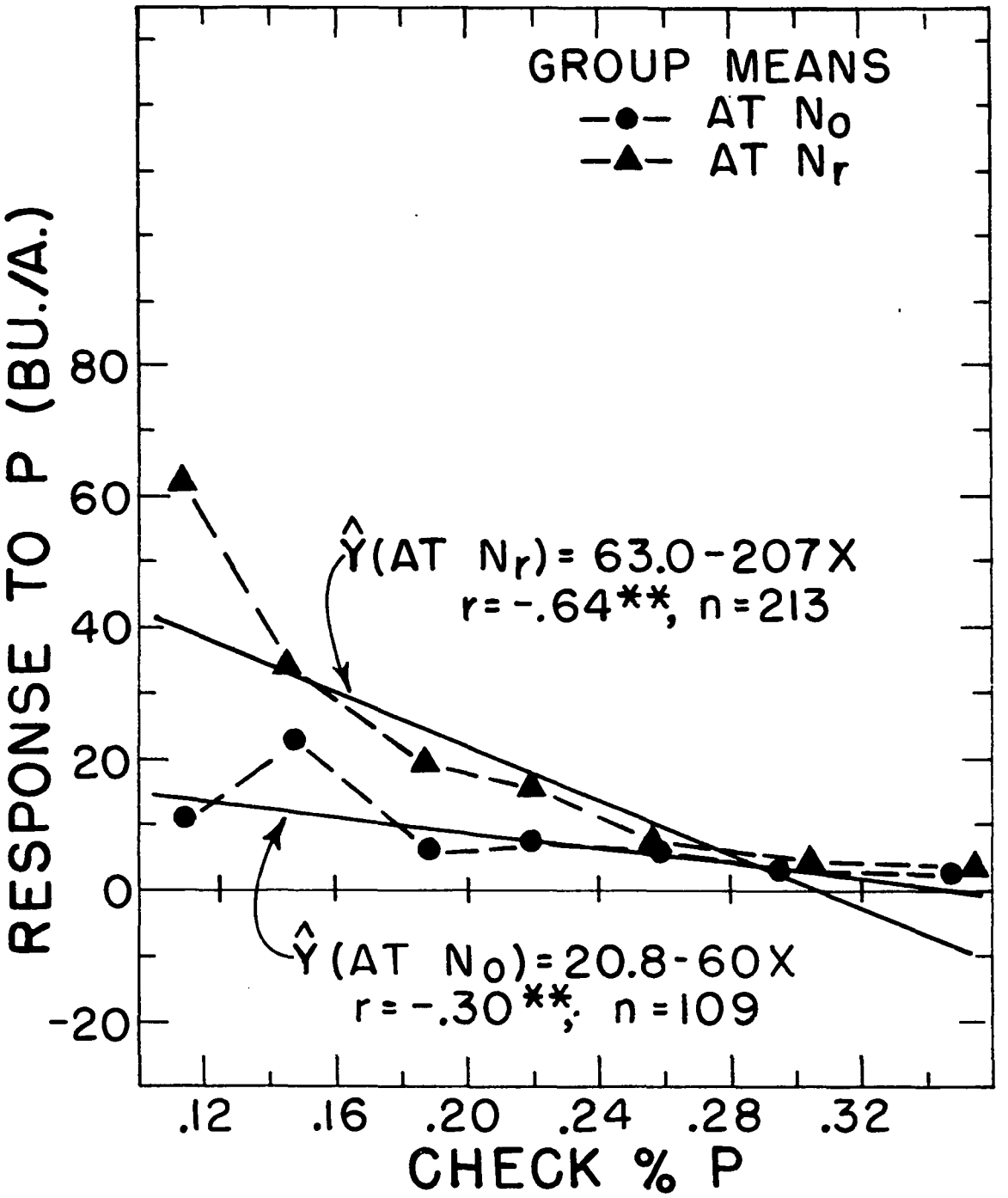

Figure 21. Regressions of the corn yield response to P fertilizer, without and with N fertilizer, on the Check percent P in the corn leaf (all P rates)

probably is due to the effect of the N fertilizer on the percent P in the leaf which is included in the relationship with the percent P at N_rP_0 but not in the one with the Check percent P.

The effect of rates of P fertilizer on the relationship between the response to P and the percent P in the leaf at N_rP_0 is shown in Figure 22. The yield response curve rose sharply at the lowest leaf P levels but leveled rapidly after the first increment of 40 pounds of P_2O_5 as the leaf P level reached 0.20 to 0.22%P. The highly significant differences among the regression coefficients due to rates (Test 4, Table 14) indicate a P fertilizer rate x leaf percent P interaction on the response to P fertilizer.

The negative and highly significant relationship between the response to P and the soil test P in the plow-layer was linear without N but was curvilinear with N fertilizer (Figure 23). The highly significant difference between the regression coefficients (Test 5, Table 14) indicates a N fertilizer x soil test P interaction on the response to P fertilizer. The effect of P rates in the presence of N on the yield response-soil test P relationship is shown in Figure 24. Differences in the yield response among P rates were large at the lowest soil test levels but were small above a soil test level of about 3 to 4 pounds per acre. The highly significant differences among regression coefficients (Test

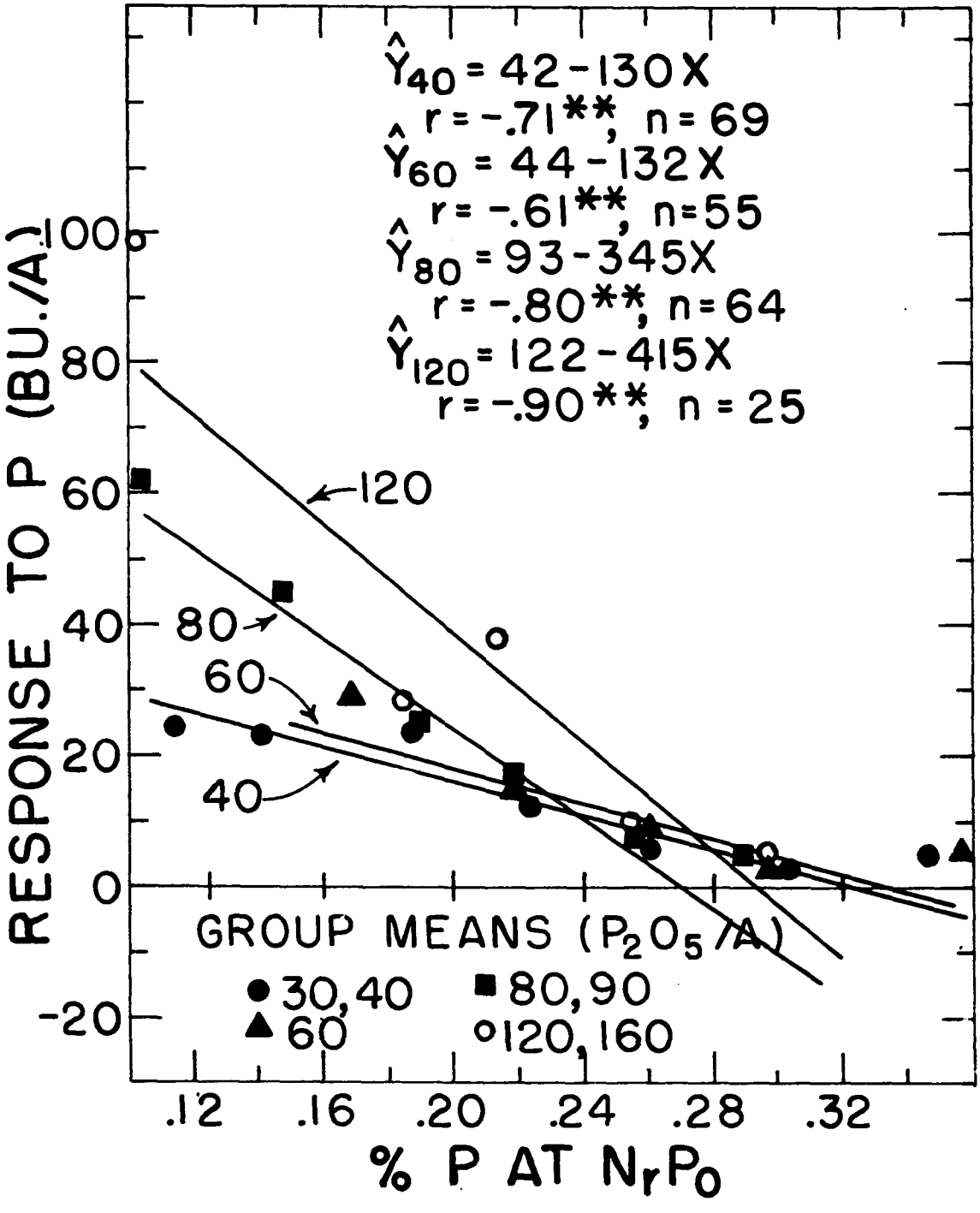

Figure 22. Regressions of the corn yield response to rates of P fertilizer on the percent P in the corn leaf at N_rP_0 (with N fertilizer)

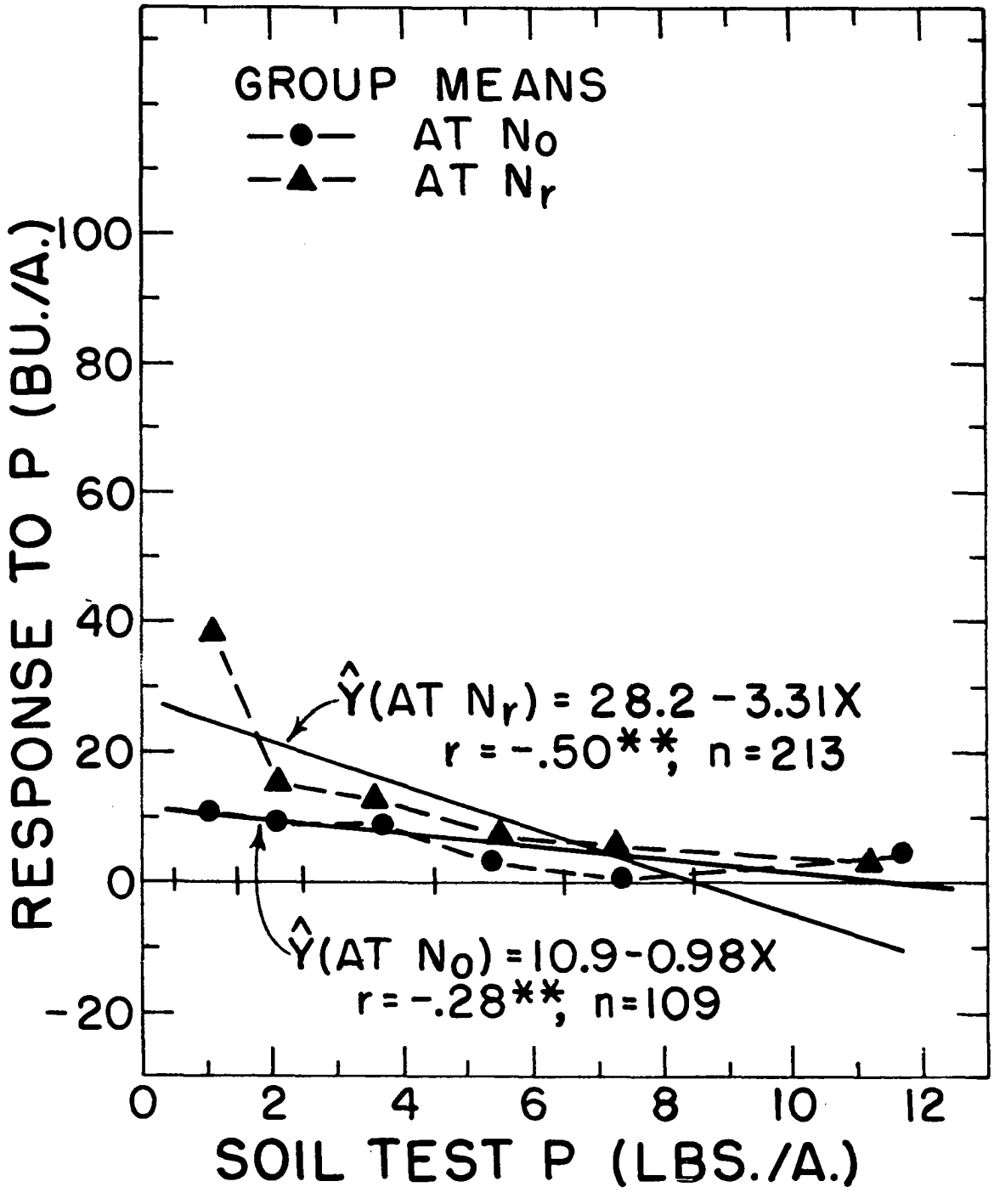

Figure 23. Regressions of the corn yield response to P fertilizer, without and with N fertilizer, on the soil test P in the plow-layer (all P rates)

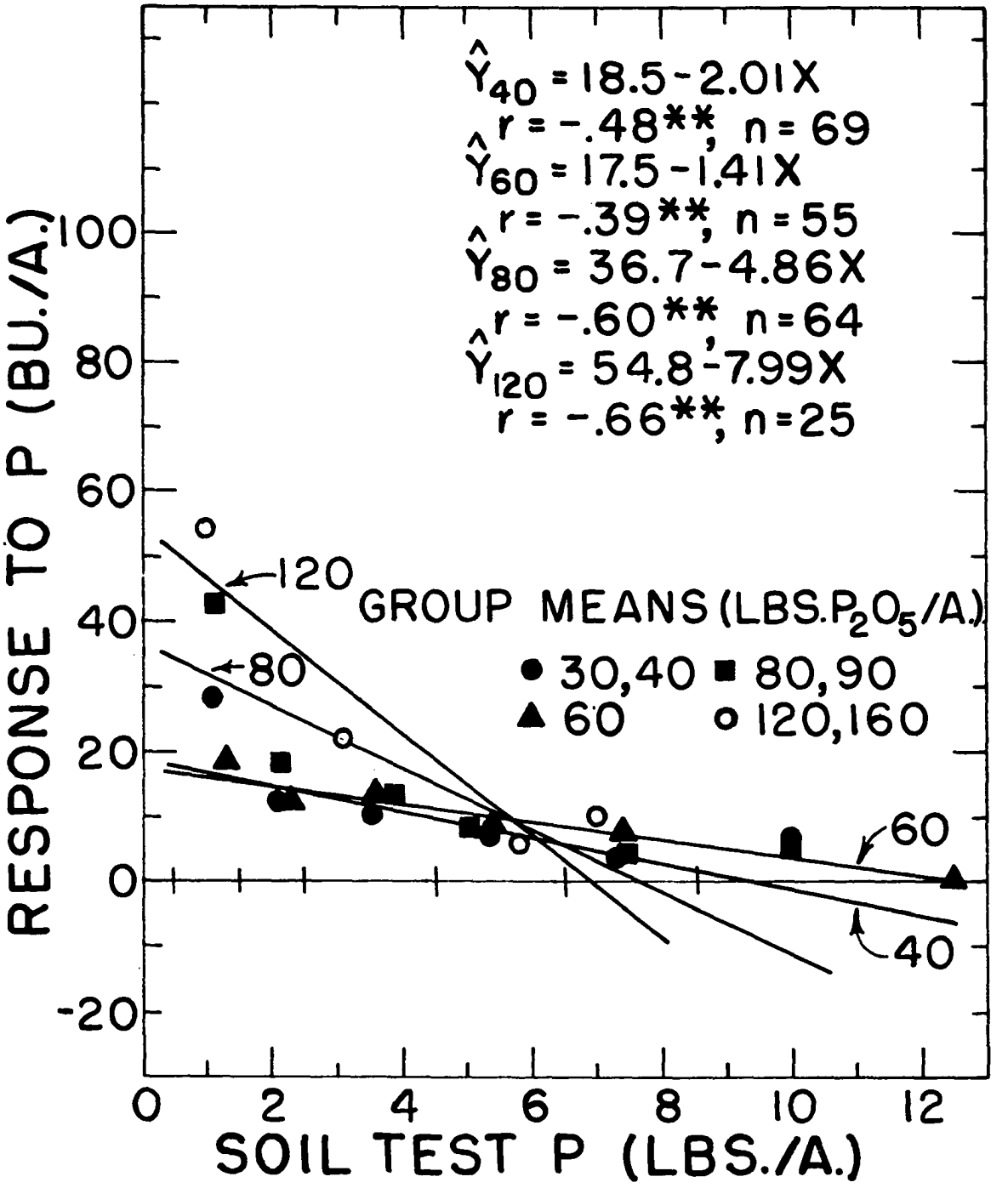

Figure 24. Regressions of the corn yield response to rates of P fertilizer on the soil test P in the plow-layer (with N fertilizer)

6, Table 14) indicate a P fertilizer rate x soil test P interaction on the response to P fertilizer.

The yield responses to P fertilizer have differed in various soil areas. The regressions of the response to P on the soil test P in two broad groups of Iowa soils are shown in Figure 25. The relationship was curvilinear on the soils in the Clarion-Webster, Marcus-Primghar-Sac, Galva-Primghar-Sac and Moody Soil Association Areas and on the Ida and Southwestern Iowa Bottomland soils. It was nearly linear on the soils in the Carrington-Clyde, Fayette-Downs, Tama-Muscatine, Mahaska-Taintor, Grundy-Haig and Marshall Soil Association Areas. The regression coefficients and the adjusted means for the two groups of soils were significantly different (Test 7, Table 14). The different yield responses to P fertilizer on most of the soils in the two groups probably are due to the differences in the P availability in the subsoils. However, as has been mentioned previously, the soil test P in the subsoil of the Carrington, Floyd and Clyde soils often has been low but these soils have responded similarly to P fertilizer as the soils with a higher soil test P in the subsoil.

Of particular interest in this study is the comparison of leaf analysis and soil test methods for predicting corn yield responses to P fertilizer. The fraction of the variations in the yield response to P explained by linear regression (r^2) was about twice as high in the regression of

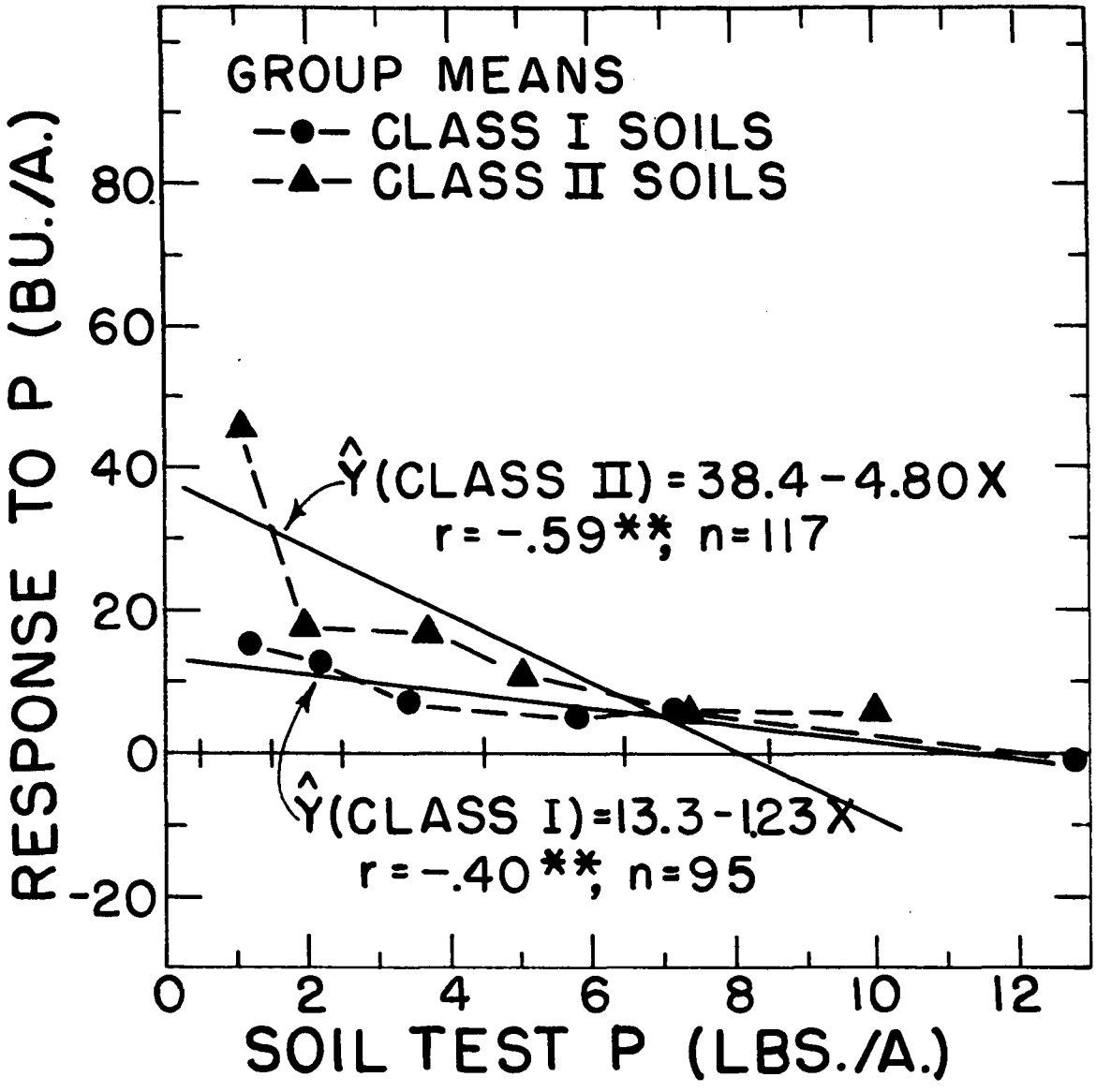

Figure 25. Regressions of the corn yield response to P fertilizer of two classes of soils on the soil test P in the plow-layer (all P rates, with N fertilizer). The soils on which corn responded less to P (Class I) included Carrington, Floyd, Clyde, Fayette, Downs, Tama, Muscatine, Mahaska, Taintor, Grundy, Haig and Marshall soils. Those on which corn responded more to P (Class II) included Clarion, Nicollet, Webster, Marcus, Primghar, Galva, Moody, Ida and Southwestern Iowa Bottomland soils

response on the percent P of the N_rP_0 treatment than in the regression of response on the soil test P (Table 15). The fraction of the yield response variations explained by using the Check percent P was intermediate between the percent P at N_rP_0 and the soil test P. Although the Check percent P will be used in most practical applications, the highest precision in estimating the response to P will most likely lie between that of the Check percent P and that of the percent P of the N_rP_0 treatment if the effect of N fertilizer on the P content in the leaf is included in the multiple regression. Curvilinear regression may also increase the fraction of the variations explained by regression. The precision of the yield response predictions on the soil test P also should be increased by using curvilinear regression and including the soil test P level in the subsoil in the multiple regression. Although the precise value of the leaf analysis and soil test

Table 15. The fraction of the variations in the yield response to P fertilizer explained by linear regression (r^2) in the regressions of yield response to P on the soil test P and percent P in the corn leaf (with N fertilizer)

P rate (lbs. P_2O_5/A.)	n^a	r^2 of the response to P on: Soil test P	Check percent P	Percent P at N_rP_0
30, 40	69	0.24	0.44	0.50
60	55	.15	.16	.37
80, 90	64	.36	.51	.64
120, 160	25	.43	.81	.81
All	213	.25	.41	.52

[a]n = number of observations.

methods for predicting yield responses to P fertilizer cannot be determined in these simple relationships, the value of leaf analysis appears promising enough to justify further investigation by multiple regression analyses.

The P availability in the soil as indicated by the percent P in the corn leaf or the soil test P level also affected the yield response to N fertilizer. The relationship between the response to N and the Check percent P in the corn leaf was not significant without P fertilizer but was negative, highly significant and curvilinear with P fertilizer (Figure 26). The highly significant difference between the regression coefficients without and with P indicates a P fertilizer x Check percent P interaction on the response to N fertilizer (Test 1, Table 16). The relationship between the response to N and soil test P without P fertilizer was positive, significant and linear but was negative, significant and perhaps curvilinear with P fertilizer (Figure 27). The highly significant difference between the regression coefficients indicates a P fertilizer x soil test P interaction on the response to N fertilizer (Test 2, Table 16).

The N availability in the soil affected the yield response to P fertilizer. The linear and significant relationships between the response to P and the Check percent N were positive without N fertilizer and negative with N fertilizer (Figure 28). The highly significant difference between the

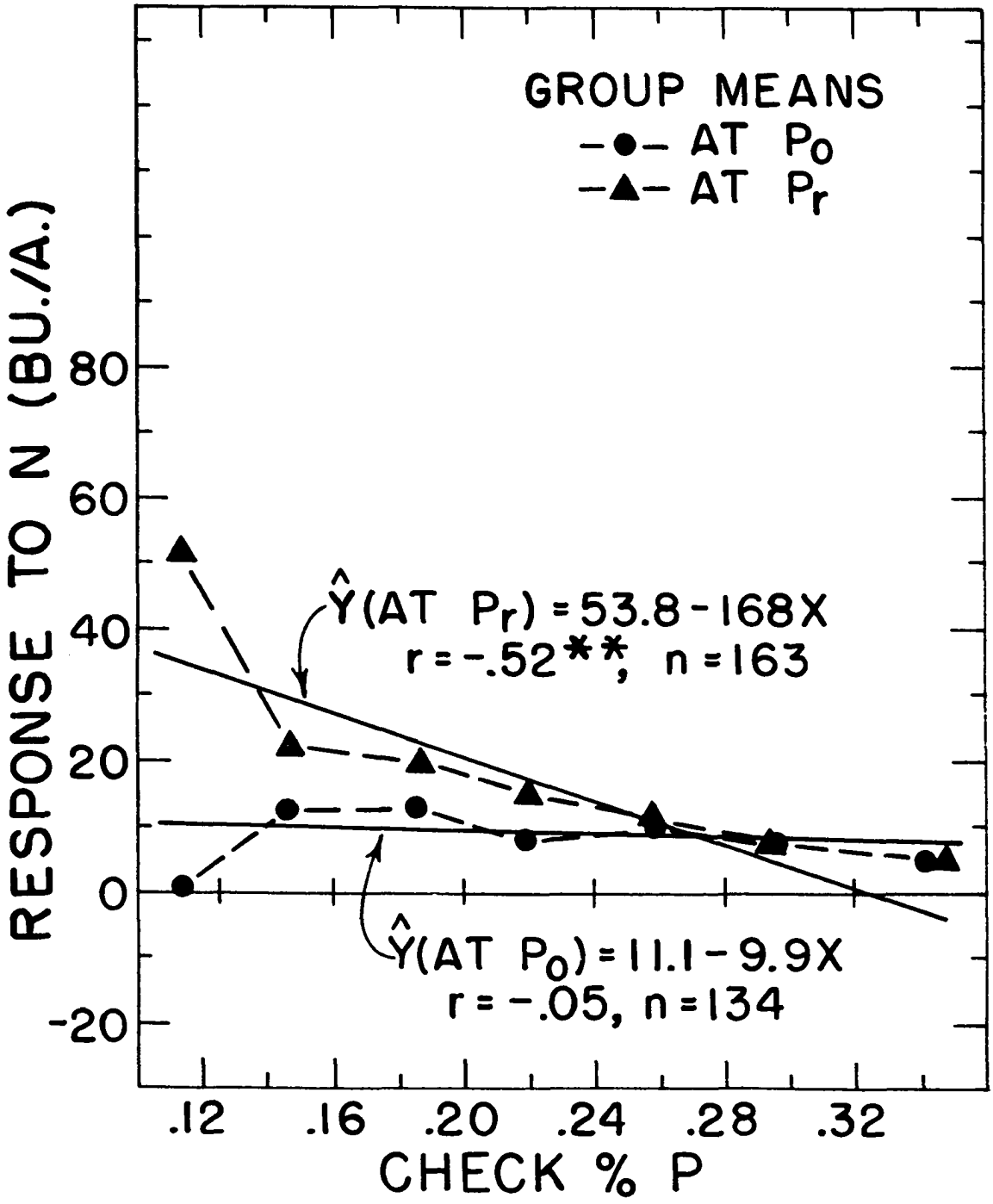

Figure 26. Regressions of the corn yield response to N fertilizer, without and with P fertilizer, on the Check percent P in the corn leaf (all N rates)

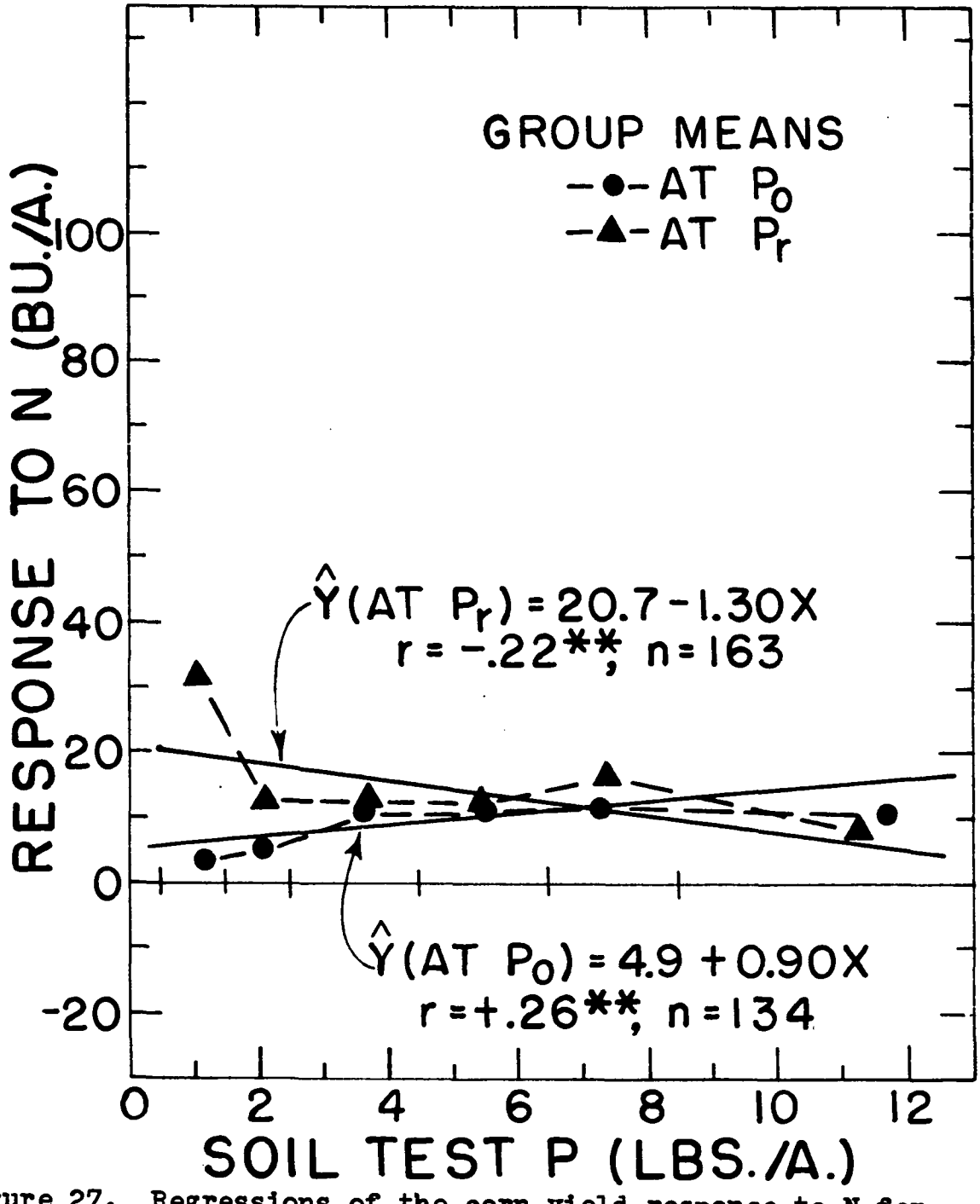

Figure 27. Regressions of the corn yield response to N fertilizer, without and with P fertilizer, on the soil test P in the plow-layer (all N rates)

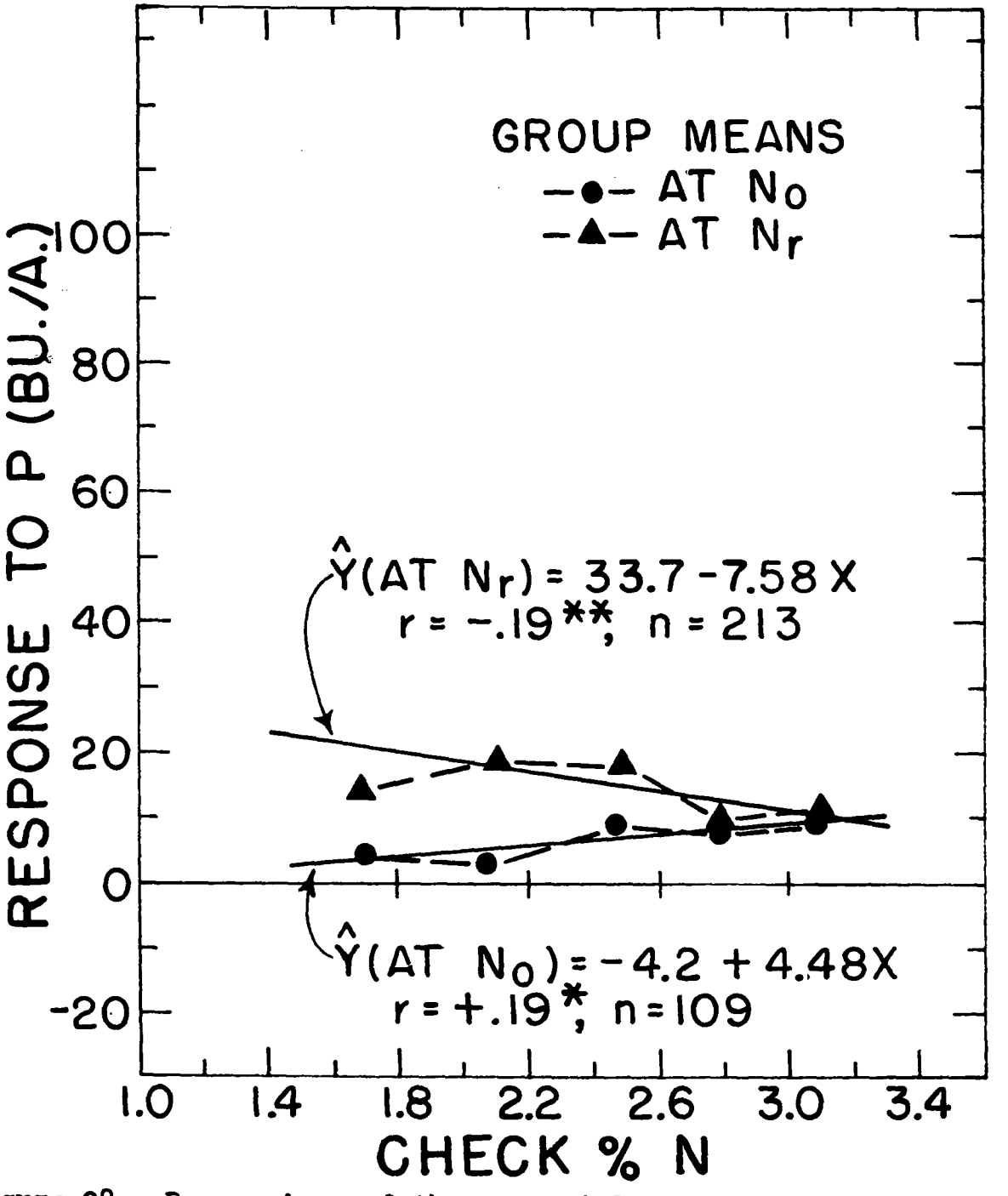

Figure 28. Regressions of the corn yield response to P fertilizer, without and with N fertilizer, on the Check percent N in the corn leaf (all P rates)

Table 16. Tests of significance between or among the regression coefficients and adjusted means in the relationships involving the yield response to N and P fertilizer

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Response to N on Check percent P, at P_0 and P_r (Figure 26)	Within	293	139.3	
		Reg. Coef.	1	4527.0	39.5**
		Common	294	154.2	
		Adj. Means	1	2376.8	15.4**
2.	Response to N on the soil test P, at P_0 and P_r (Figure 27)	Within	293	168.0	
		Reg. Coef.	1	2513.2	15.0**
		Common	294	176.0	
		Adj. Means	1	2902.9	16.5**
3.	Response to P on the Check percent N, at N_0 and N_r (Figure 28)	Within	318	207.9	
		Reg. Coef.	1	1818.3	8.7**
		Common	319	212.9	
		Adj. Means	1	4823.9	22.6**
4.	Response to P on the Check percent N and the percent N of the N_rP_0 treatment, at N_r	Within	422	251.7	
		Reg. Coef.	1	2314.5	9.2**
		Common	423	256.6	
		Adj. Means	1	669.4	2.61
5.	Response to N on the Check percent N, at P_0 and P_r (Figure 29)	Within	293	114.8	
		Reg. Coef.	1	2158.5	18.8**
		Common	294	121.8	
		Adj. Means	1	3106.9	25.5**
6.	Response to N on the Check percent N and percent N of the N_0P_r treatment, at P_r	Within	322	134.7	
		Reg. Coef.	1	22.5	0.17
		Common	323	134.3	
		Adj. Means	1	284.3	2.12
7.	Response to rates of N on the percent N of the N_0P_r treatment, at P_r (Figure 30)	Within	155	71.8	
		Reg. Coef.	3	1264.3	17.6**
		Common	158	94.4	
		Adj. Means	3	1058.1	11.2**

regression coefficients indicates a N fertilizer x Check percent N interaction on the response to P fertilizer (Test 3, Table 16). The relationship between the yield response to P and the percent N in the leaf of the N_rP_0 treatment was similar to the one between the response to P and the Check percent N, with N fertilizer, except that the correlation and regression coefficients were higher in the former (r = -0.38**, b = -21.3) than in the latter (r = -0.19**, b = -7.6). The significant difference between the regression coefficients of these two relationships (Test 4, Table 16) may reflect only the effect of N fertilizer in increasing the percent N in the leaf and the compression of the leaf N observations within a narrower range.

The relationships between the yield response to N and the Check percent N, without and with P fertilizer, were negative, linear and highly significant (Figure 29). The highly significant difference between the regression coefficients without and with P (Test 5, Table 16) indicates a P fertilizer x Check percent N interaction on the yield response to N fertilizer. With P fertilizer, the relationship between the response to N and the percent N in the leaf of the N_0P_r treatment had a higher correlation (r = -0.75**) than the one between the response to N and the Check percent N (r = -0.62**). There was no difference between the regression coefficients or adjusted means (Test 6, Table 16).

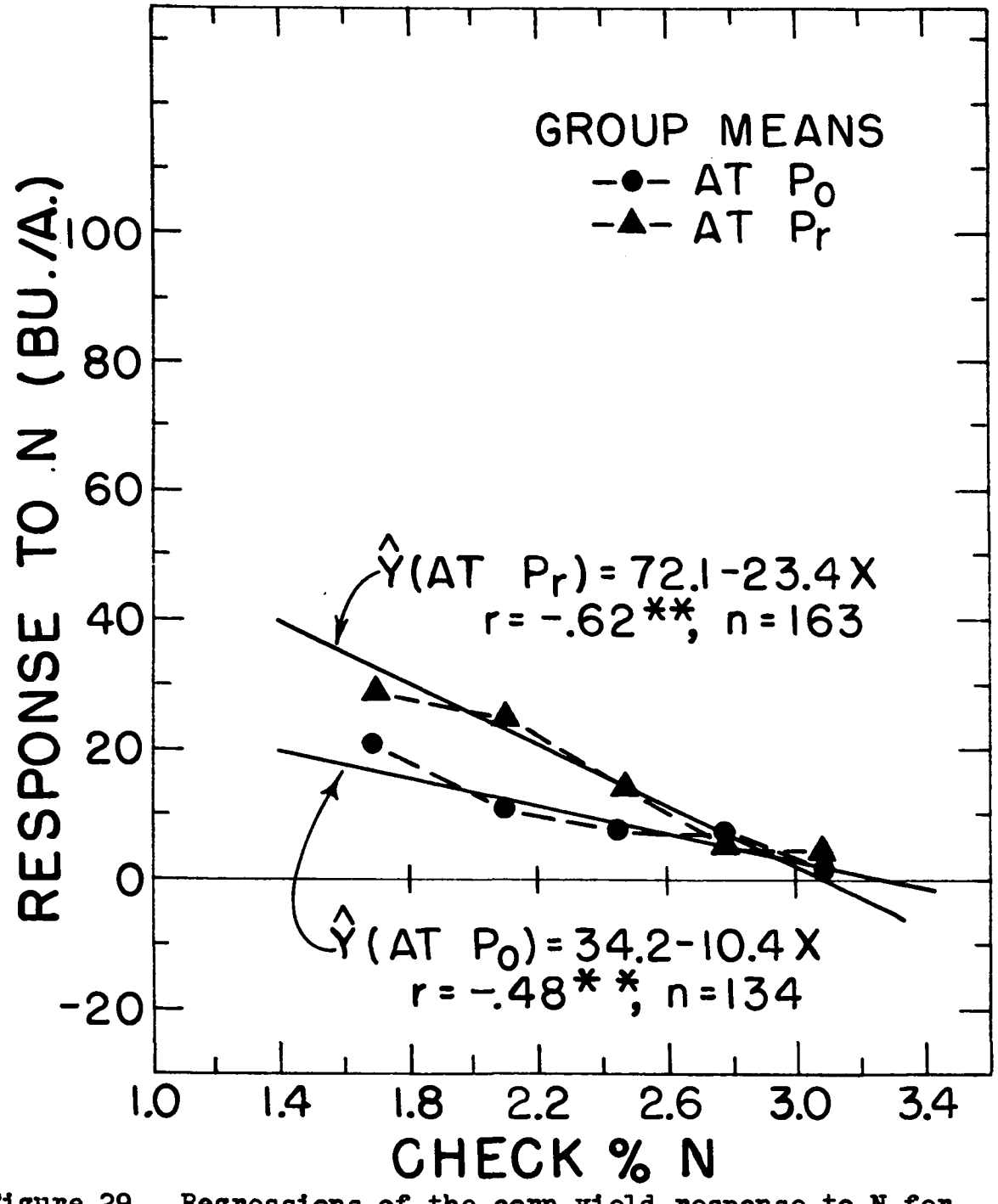

Figure 29. Regressions of the corn yield response to N fertilizer, without and with P fertilizer, on the Check percent N in the corn leaf (all N rates)

The effect of rates of N fertilizer on the regressions of yield response to N on the percent N in the corn leaf at N_0P_r is shown in Figure 30. As shown by the regressions and groups averages, the yield response curve to N fertilizer varied with the leaf N level. The differences among the regression coefficients of the various rates indicate a N fertilizer x leaf percent N interaction on the response to N fertilizer (Test 7, Table 16).

Since soil test N data were not available for all fields, the percent N in the Check or N_0P_r treatment was the only measure of the N availability in the soil. The comparative value of the leaf analysis and the N soil test methods for predicting the yield response to N fertilizer may be approximated by comparing the coefficients of determination (r^2) of the regressions of the response to N on the leaf N in this study and those of the response to N on the soil test N reported by Hanway and Dumenil (37)(Table 17). Data from many of the same experiments were used in both comparisons. Although no tests of significance can be made of the differences, the leaf N content appears to be as good as and perhaps somewhat better than the soil test N for predicting the yield response to N fertilizer.

The correlations involving the soil test N did not include data from corn following a legume meadow but the correlations with the leaf N content did include first-year corn.

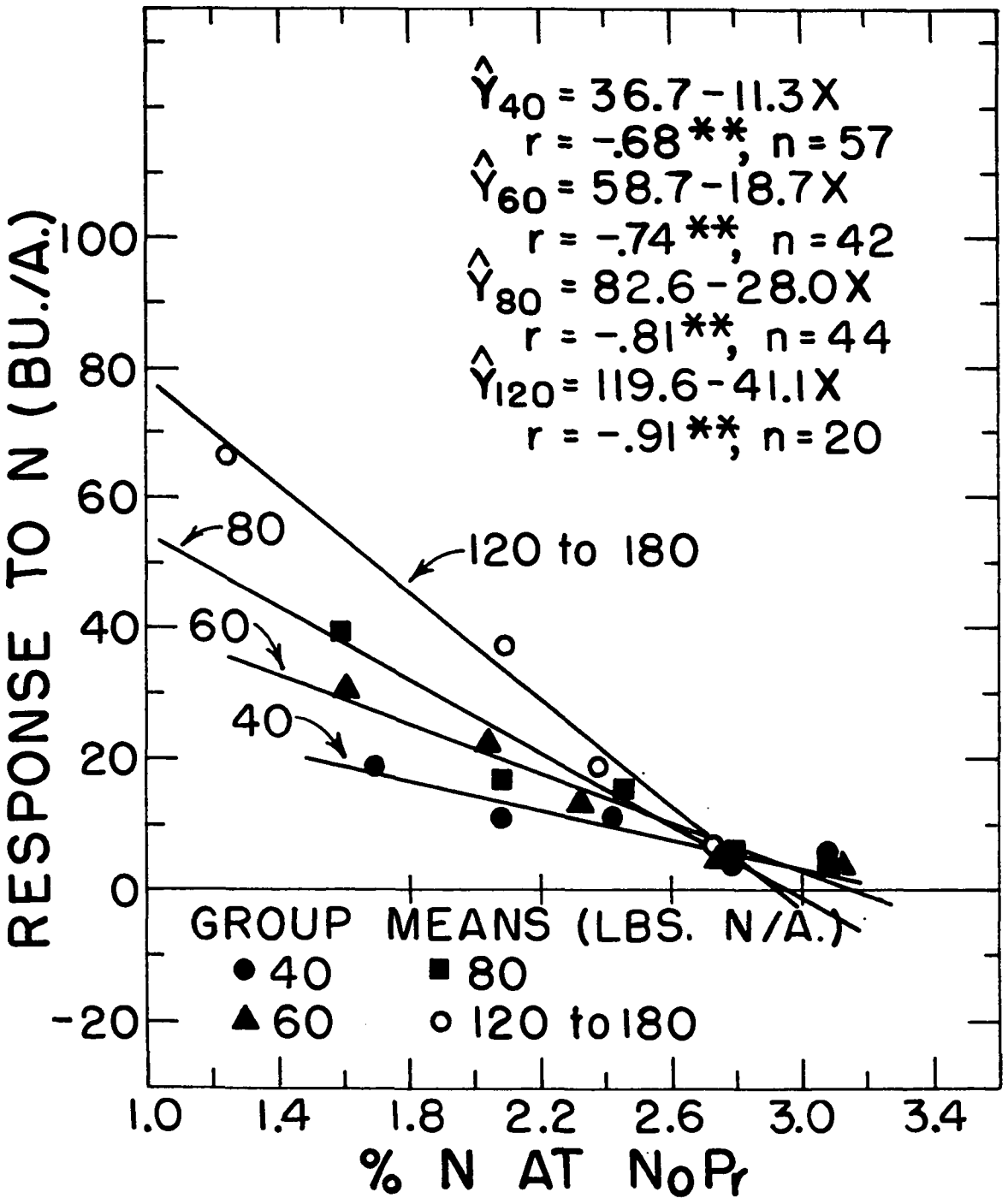

Figure 30. Regressions of the corn yield response to rates of N fertilizer on the percent N in the corn leaf at N_0P_r (with P fertilizer)

Table 17. The fraction of the variations in the yield response to N explained by linear regression (r^2) in the regressions of the response to N on the percent N in the corn leaf and of the log of the response to N on the soil test N (with P fertilizer)

N rate (lbs. N/A.)	n^a	r^2 of the response to N on: Check percent N	Percent N at N_0P_r	n^b	r^2 of the log of the response to N on soil test N[c]
40	57	0.47	0.47	60	0.45
60	42	.52	.54	25	.28
80	44	.40	.65	46	.44
120	} 20	.63	.83	5	.34
180				5	.23

[a]n = number of observations.

[b]n = number of experiments.

[c]Data from Table 1, Hanway and Dumenil (37).

Tyner et al. (82) found that correlations between yields and leaf N were somewhat lower on corn following a legume than on other corn crops. They concluded that the release of N from legume residues after leaf samples were taken at silking contributed to the reduced correlations.

The difference between the yield response correlations with the Check percent N and the percent N of the N_0P_r treatment at rates of 80 and 120 to 180 pounds of N appeared to be due, in part, to the large responses to N on Experiment 26 on Ida silt loam. The addition of P fertilizer decreased the percent N in the leaf markedly so that the large N responses with P were more in line with the other observations in the

correlations with the percent N at N_0P_r than in those with the Check percent N. For example, omitting the two observations from this experiment increased the r^2 between the response to N and the Check percent N in the leaf at the 80-pound rate from 0.40 to 0.55.

In the experiments where methods of application were compared, broadcast and plowed-under application of P fertilizer gave larger yield responses to P than broadcast and disked-in application (Table 11). These larger responses were related to larger increases in the percent P in the leaf from plowed-under than from disked-in P. Previous data (22) indicated little yield difference among methods of N application. The method of application which was the same for both N and P in almost all of the experiments might be expected to affect the responses to P but have little effect on the responses to N fertilizer.

There appeared to be little relationship between stand level and the yield response to N or P. For all observations, the correlation coefficients between stand level and the response to N and P were 0.27** and 0.17*, respectively. However, if the observations from Experiment 26 were omitted, the correlation coefficients between stand level and the response to N and P were 0.02 and -0.07, respectively.

Another factor that may be useful in the prediction of the yield response due to N and P fertilization is the yield

of the unfertilized treatment (Check yield). The relationship between yield response and Check yield would be expected to be negative. If the Check yield is known or can be estimated closely, the addition of this variable to the regression equation may increase the precision in the yield response prediction. For the many cases in which the Check yield will not be known, an alternative regression equation for predicting the yield response from leaf composition and other factors must be calculated without the Check yield variable.

In summary, the hypothesis to be tested is that the change in yield from N and P fertilization may be expressed as a function of the following factors: (1) percent N without fertilizer (curvilinear), (2) percent P without fertilizer (curvilinear), (3) soil test P level (curvilinear), (4) N fertilizer level (curvilinear), (5) P fertilizer level (curvilinear), (6) NP fertilizer interaction, (7) N fertilizer x percent N interaction, (8) N fertilizer x percent P interaction, (9) P fertilizer x percent N interaction, (10) P fertilizer x percent P interaction, (11) N fertilizer x soil test P interaction, (12) P fertilizer x soil test P interaction, (13) percent N x percent P interaction, (14) percent N x soil test P interaction, (15) subsoil test P, (16) stand level, (17) method of application and (18) unfertilized yield level. Except for the last variable, the variables are the same for

the regression analyses involving both the change in yield and the change in percent P of the corn leaf.

4. Yield

In the last phase of this study, the factors that might be used to predict the corn yield were investigated. If the yield of the unfertilized corn is known, the yield may be estimated by the addition of the yield response prediction due to N and P fertilization. However, if the yield of corn with any N and P fertilizer treatment is to be estimated, data on the unfertilized yield, the leaf composition of the unfertilized corn and its interactions with N and P fertilizer levels probably will not be available.

The relationships between the yield and various available factors for predicting the yield of any N and P fertilizer treatment were investigated. The discussion in the previous section has shown that the leaf composition will reflect the availability of the N and P in the soil and the fertilizer. However, if only soil tests are used to predict the yield of fertilized corn, the N and P fertilizer effects on yield also must be included. The factors used to predict the corn yield included the leaf N and P levels and their interaction, the soil test P level and its interactions with N and P fertilizer, the soil test P in the subsoil, the stand level, the N and P fertilizer levels and the NP fertilizer interaction.

The yield and the percent P in the corn leaf were significantly and positively correlated at all fertilizer treatments and the relationship tended to be curvilinear, particularly with N fertilizer (Figure 31). The differences among the regression coefficients of yield on the leaf P of all fertilizer treatments were significant only at the 8% level (Test 1, Table 18). However, these differences among regression coefficients were due solely to the regression coefficient of the N_rP_r treatment which differed significantly from the others. The lower regression coefficient of the N_rP_r treatment may be due to fitting a linear regression to what appears to be a curvilinear relationship. More of the observations of the N_rP_r treatment also occurred near the approximate critical level. Fitting the yield-leaf P relationships of the various fertilizer treatments to a curvilinear function may eliminate the apparent fertilizer x leaf P level interaction on yield. The adjusted yield means among the fertilizer treatments were significantly different (Test 1, Table 18). The N treatments had a higher yield than those without N at any leaf P level. This would be expected since the effect of N fertilizer on the leaf N level is only partially accounted for in these relationships by the correlation between the leaf N and P contents.

The corn yield and the percent N in the leaf were significantly and positively correlated at all fertilizer treat-

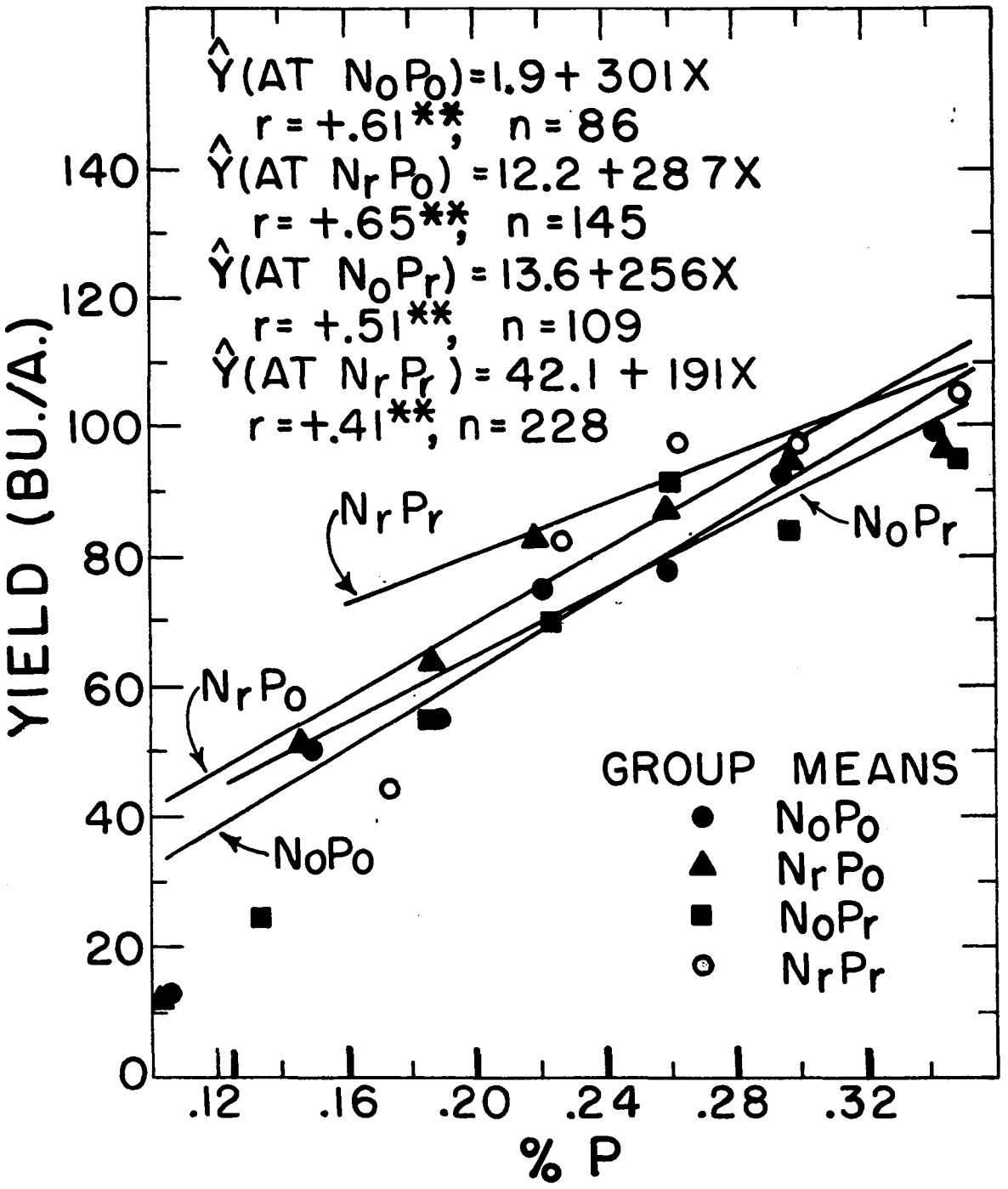

Figure 31. Regressions of the corn yield at the N_0P_0, N_rP_0, N_0P_r and N_rP_r treatments on the percent P in the corn leaf of the respective treatments (all N and/or P rates)

Table 18. Tests of significance between or among the regression coefficients and the adjusted means in the relationships involving the corn yield

Test	Regressions of	Source of variation	d.f.	M.S.	F
1.	Yield on percent P, at N_0P_0, N_rP_0, N_0P_r and N_rP_r (Figure 31)	Within	560	335.6	
		Reg. Coef.	3	787.3	2.34[a]
		N_rP_r vs. others	1	2110.0	6.29*
		Among N_0P_0, N_rP_0, N_0P_r	2	126.0	0.38
		Common	563	338.0	
		Adj. Means	3	3844.3	11.4**
2.	Yield on percent N, at N_0P_0, N_rP_0, N_0P_r and N_rP_r (Figure 32)	Within	560	361.4	
		Reg. Coef.	3	488.3	1.35
		Common	563	362.0	
		Adj. Means	3	7480.0	20.6**
3.	Yield on soil test P, at N_0P_0, N_rP_0, N_0P_r and N_rP_r (Figure 33)	Within	560	454.5	
		Reg. Coef.	3	1981.3	4.36*
		Common	563	462.6	
		Adj. Means	3	12778.0	27.6**
4.	Yield on soil test P, at N_0P_0 and N_rP_0 (Figure 33)	Within	227	497.4	
		Reg. Coef.	1	764.0	1.54
		Common	228	498.5	
		Adj. Means	1	3144.0	6.31*
5.	Yield on stand level, at N_0P_0, N_rP_0, N_0P_r and N_rP_r (Figure 34)	Within	560	441.5	
		Reg. Coef.	3	257.3	0.58
		Common	563	440.5	
		Adj. Means	3	12383.3	28.1**

[a]Significant at the 8% level.

ments and the relationships tended to be curvilinear at all treatments (Figure 32). The differences among the regression coefficients were not significant but the differences among the adjusted means were highly significant (Test 2, Table 18). The higher yields of the treatments with P than those without

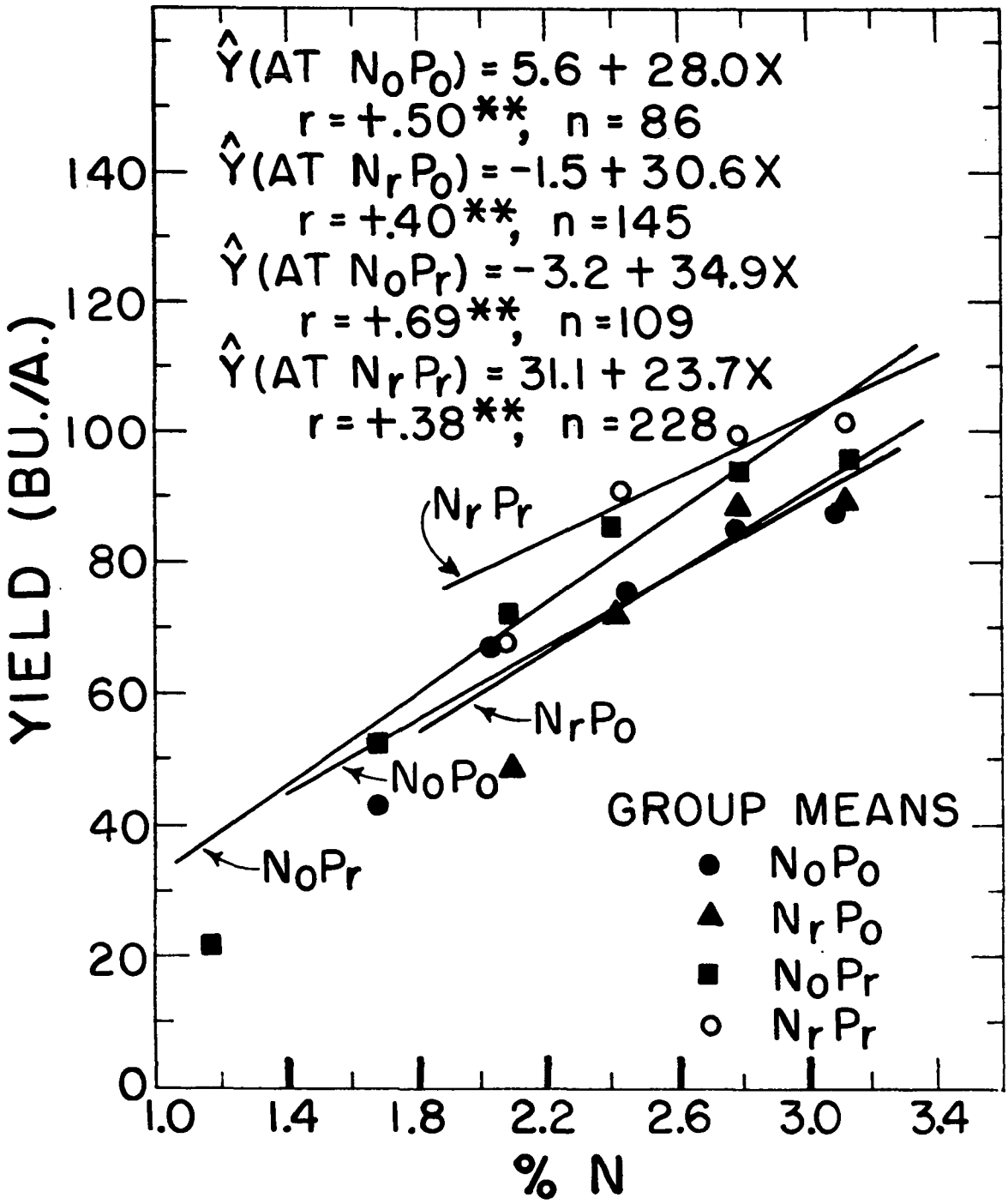

Figure 32. Regressions of the corn yield at the N_0P_0, N_rP_0, N_0P_r and N_rP_r treatments on the percent N in the corn leaf of the respective treatments (all N and/or P rates)

P at any leaf N level would be expected since the effect of P fertilizer on the leaf P level is not fully accounted for in these relationships.

The relationships between yield and soil test P varied considerably with the fertilizer treatment. Without P fertilizer, at N_0P_0 and N_rP_0, the yield and soil test P level were significantly and positively correlated and the relationships tended to be curvilinear. With P fertilizer, at N_0P_r and N_rP_r, there was little relationship between yield and soil test P level (Figure 33). The regression coefficients and adjusted means were significantly different among the treatments (Test 3, Table 18). The differences among the regression coefficients indicate a N and P fertilizer x soil test P interaction on yield. This shows that the effect of the N and P fertilizer levels on yield also must be included if the soil test P level is to be used to estimate corn yields.

Since the P fertilizer gave similar yields at all except the lowest soil test P levels, the differences among the regression coefficients of the yield-soil test P relationships appeared to be due primarily to the effect of the P fertilizer. In the relationships not confounded by the effect of P fertilizer, the N_0P_0 and N_rP_0 treatments, the regression coefficients were not significantly different (Test 4, Table 18). However, the correlation coefficient between yield and

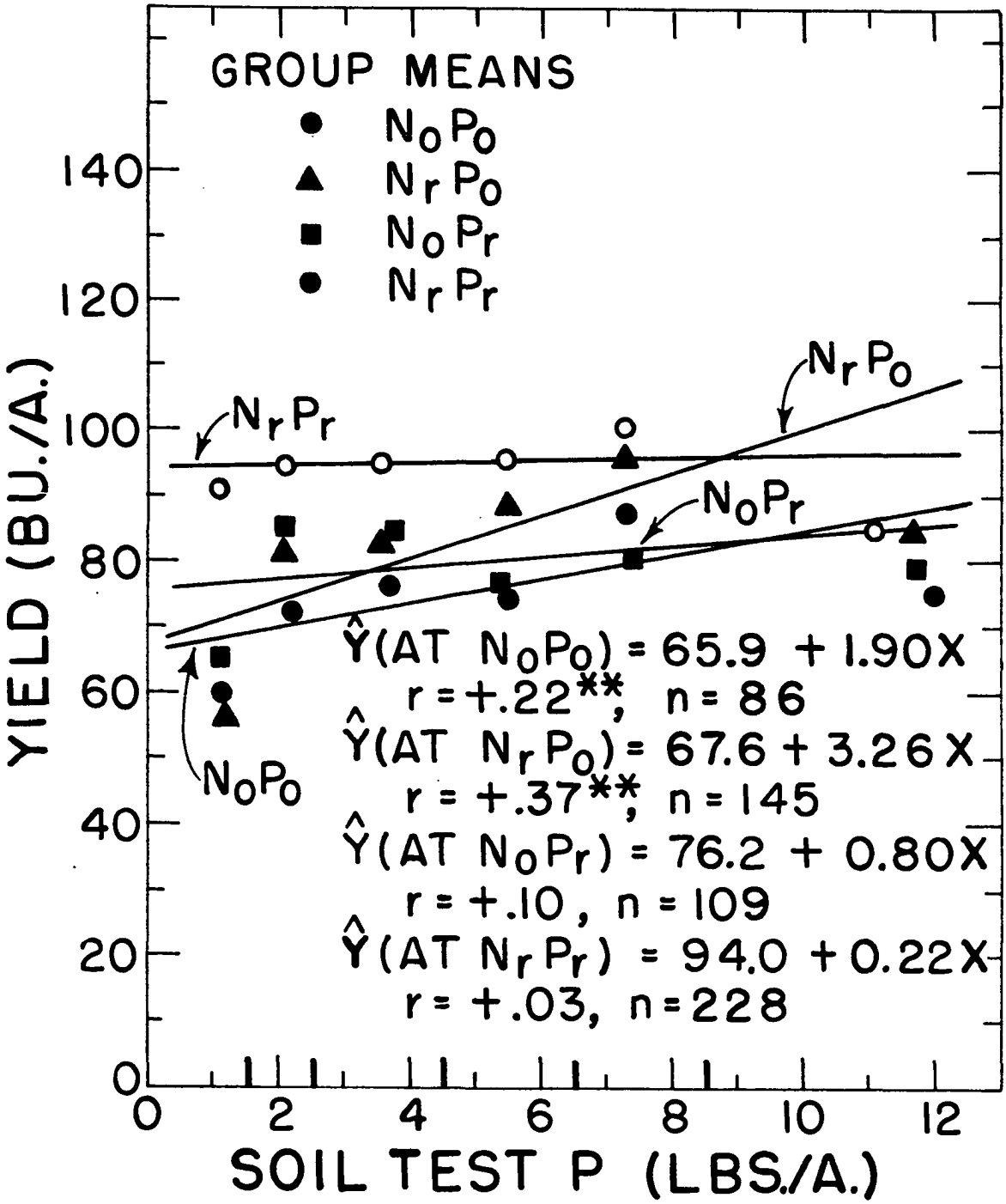

Figure 33. Regressions of the corn yield at the N_0P_0, N_rP_0, N_0P_r and N_rP_r treatments on the soil test P in the plow-layer (all N and/or P rates)

soil test P was higher with N ($r = 0.37^{**}$) than without N ($r = 0.22^{*}$).

The linear regression of yield on the leaf P level ($r^2 = 0.37$) explains more of the variations in yield of the unfertilized corn than the regression of yield on the soil test P level ($r^2 = 0.05$). The leaf P content reflects the N availability in the soil through its high correlation with the leaf N content and the effects of other variables on crop growth up to the time of leaf sampling. Most of these effects, however, are not included in the yield-soil test P relationships. The coefficients of determination (r^2) between yield and leaf P and yield and soil test P with N fertilizer (N_rP_0) were 0.42 and 0.14, respectively. Thus, the relative difference between the leaf P and soil test P levels for yield prediction is similar without and with N fertilizer.

The yield and the stand level at all fertilizer treatments were significantly and positively correlated and the relationships appeared to be curvilinear (Figure 34). There were no significant differences among the regression coefficients (Test 5, Table 18). The absence of a fertilizer treatment x stand level interaction on yield was unexpected since this interaction has been reported frequently in the literature (22, 25, 41, 56).

The method of P fertilizer application was not included as a variable in the yield prediction equation although it had

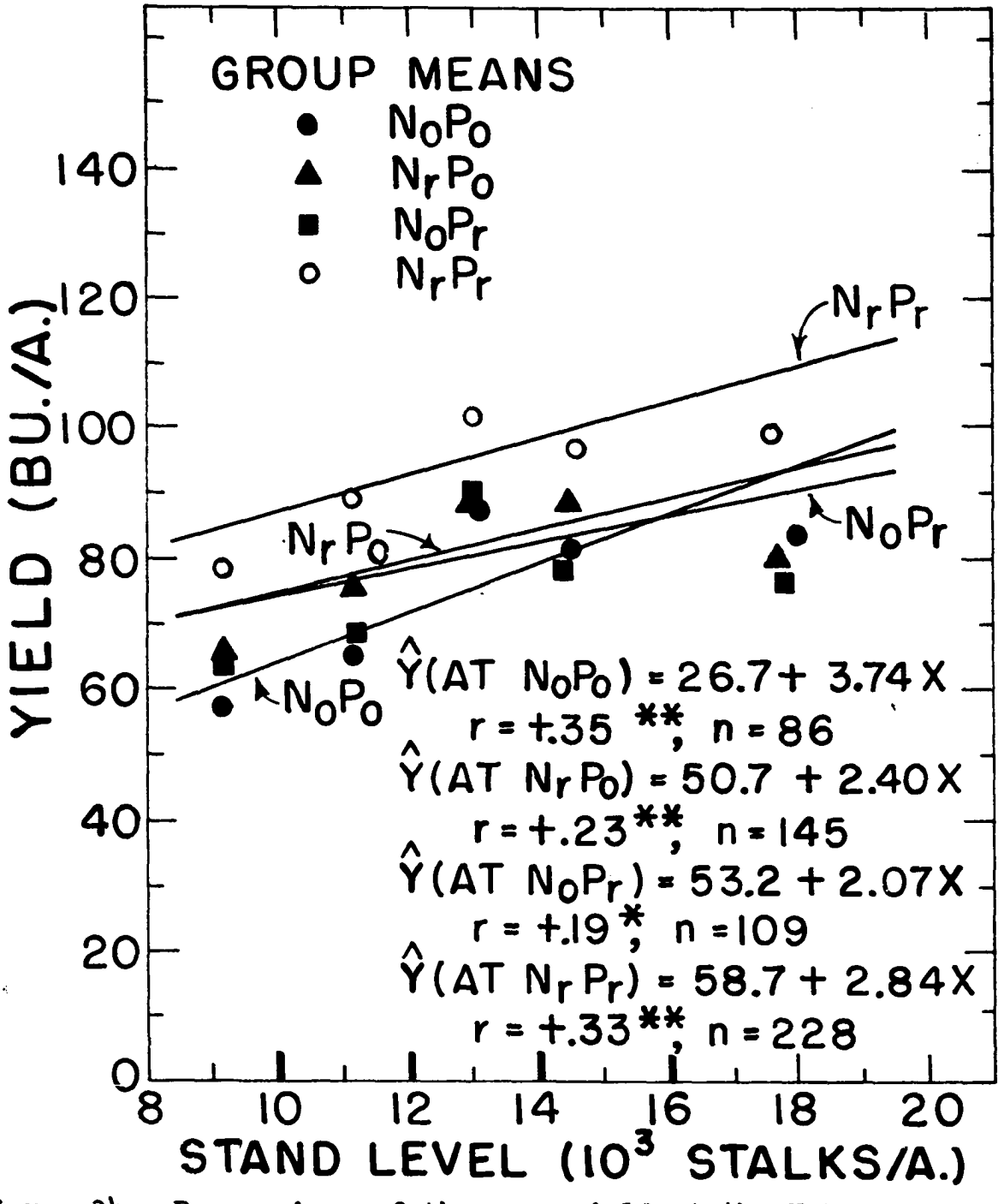

Figure 34. Regressions of the corn yield at the N_0P_0, N_rP_0, N_0P_r and N_rP_r treatments on the stand level (all N and/or P rates)

a significant effect on the change in the leaf P and yield response to P fertilizer. The effect of the method of P application on yield was confounded with season, soil area, time of plowing and previous crop management. Most of the experiments having disked-in fertilizers were located in northeastern Iowa from 1953 to and including 1956 when climatic conditions generally were quite favorable for high corn yields. Most of these fields also were plowed in the fall and the corn followed a meadow crop. The fields with plowed-under applications were plowed in the spring except the ones with methods comparisons which were plowed in the fall. The confounding of the above-mentioned factors with method of application appeared to be less in the relationships with the change in percent P and change in yield than with the leaf P level and yield. Most of the confounding effect appeared to be associated with the initial leaf P or yield level (without fertilizer) rather than with the changes in either one due to fertilization.

In summary, the hypothesis to be tested is that the yield of corn at any N or P fertilizer treatment may be expressed as a function of the following factors: (1) percent N in the corn leaf (curvilinear), (2) percent P in the corn leaf (curvilinear), (3) percent N x percent P interaction, (4) N fertilizer level (curvilinear), (5) P fertilizer level (curvilinear), (6) NP fertilizer interaction, (7) soil test P level

(curvilinear), (8) N fertilizer x soil test P interaction, (9) P fertilizer x soil test P interaction, (10) subsoil test P level and (11) stand level (curvilinear).

C. Multiple Regression Analyses

1. The multiple regression model

In the preliminary investigations, relationships between or among the variables[1] were studied to determine which ones should be included in the multiple regression model for each of the following dependent variates: the change in the percent P in the corn leaf due to N and P fertilization, the percent P in the corn leaf at any level of N and P fertilization, the change in the corn yield due to N and P fertilization and the corn yield at any level of N and P fertilization.

From the approximate relationships previously determined from the successive group means, the dependent variates appeared to be curvilinear functions of some of the variables. Interactions which were shown to be present were included only as linear x linear terms. Although the linear x linear component may account for most of the interaction effect, there was evidence from the successive group means that curvilinear

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[1]The term "variable" will refer to a factor under study whose effect in the regression model and analysis may be shown as a function of one or more variates. "Variate" refers to a single term included in the multiple regression model and analysis.

components also were present. This was indicated in some of the figures where the relationship appeared to be linear without N or P fertilizer but curvilinear with N or P fertilizer and, particularly, where converging curvilinear relationships without and with the other nutrient appeared to occur as the X variable increased. Three-factor interactions also may exist among the variables, particularly among N and P and the other variables as is indicated in several of the figures, but none was investigated in this study. Compromises in the selection of the variables had to be made due to limitations in the number of variables that could be studied with present facilities.

The general multiple regression model of the dependent variate (Y) on r fixed variates, Anderson and Bancroft (1), is assumed to be:

$$Y = \mu + \sum_{i=1}^{r} \beta_i x_i + \epsilon ,$$

where μ is the population mean, β_i is the population regression coefficient, x_i is the deviation of the X_i variate from its mean ($x_i = X_i - \bar{X}_i$), i = 1, 2 ...., r is the number of X variates and associated regression coefficients and ϵ is the true error.

The estimates of the population parameters are represented by:

$$\hat{Y} = \bar{Y} + \sum_{i=1}^{r} b_i x_i + e ,$$

where $\hat{Y}$ is the estimated dependent variate, $\bar{Y}$ is the observed mean, b_i is the estimated regression coefficient, and e is the individual residual error. The residual sum of squares, calculated along with the inverse matrix on the IBM 650 Computer, may be expressed as $(1 - R^2)\ Sy^2$ and then the reduction due to regression is R^2Sy^2, where Sy^2 is the sum of squares of the deviations of the dependent variate (Y) from the mean and R^2 is the fraction of the variations in the dependent variate due to multiple regression. In the equations employed, the X_i may be linear, square root, squared or linear x linear interaction terms.

Several forms of algebraic functions may be used to express the curvilinear relationships among variables but little work has been done with fitting data to curvilinear functions of more than three variables. Heady et al. (39) and Brown et al. (10) stated that the quadratic polynomial function has several advantages over other types, such as exponential or logarithmic functions, for predicting yields and for further economic analyses. The quadratic polynomial function therefore was used in this study for the variables showing curvilinear effects.

Heady et al. (39) tested two general types[1] of the quadratic function for their two-variable functions, a quadratic

[1]Hereinafter, the quadratic equation with squared terms and the square root transformation of a quadratic equation will be referred to as quadratic and square root functions, respectively.

equation with squared terms and a linear x linear interaction term and a square root transformation of a quadratic equation with the linear x linear interaction being a square root term. They selected the square root function as the most efficient since its coefficient of multiple determination (R^2) was larger and its residual sum of squares was smaller than the corresponding ones of the quadratic function. Brown et al. (10) also used the quadratic and square root functions; in one case, a mixed function was used by combining the quadratic function for one variable and the square root function for the other variable. The functions for their regression equations were selected primarily on the basis of the highest R^2 although logical considerations affecting the economic analyses were also involved.

The square root function fits data best where the slope of the curve initially is steep, decreases rapidly, remains near zero over a wide range of the X variable and finally changes direction. The quadratic function fits data best where the slope of the curve gradually decreases to zero and then becomes increasingly larger and of opposite sign. In the curvilinear relationships shown in the preceding figures, the change in the slope of the dependent (Y) variate with increasing level of the X variable was gradual except with the soil test P variable. The relationships with soil test P generally showed a steep slope at very low levels, a rapidly

changing slope at the low levels and a nearly constant slope approaching zero thereafter. Therefore, the quadratic function may be satisfactory for all variables except possibly the soil test P variable for which a square root function may give a better fit to the data.

Both the square root and quadratic terms were included in the preliminary calculations (the sums of squares and cross products and the correlation coefficients) for several variables in order to compare the relative efficiency of the two functions. These variables included N and P fertilizer levels, the soil test P level, percent N and P in the leaf and the Check percent P in the leaf. Only the quadratic function of the Check percent N and stand level was included since the relationships with the Check percent N showed little curvature and those with stand appeared curvilinear only with the corn yield. Additional interaction terms also were included in order to have the correct linear x linear interaction term for a mixed model. It was assumed that the linear x linear interaction term in a mixed model involving, for example, the quadratic function of the N level and the square root function of the soil test P level (P_s) would be $N \times P_s^{\frac{1}{2}}$.

Since the capacity of the IBM 650 Computer for a simultaneous calculation is 29 variates including one or more dependent variates (Y), all possible combinations of the interaction terms involved in a mixed model could not be included.

The additional variates that were added later to the change in percent P and change in yield models were based on these earlier comparisons between the quadratic and square root functions. The variables and their associated variates which were included in the regression models for all dependent variates are given in Table 19.

The linear correlation coefficients between the Y variates and their associated X variates of the square root and quadratic functions were first examined (Table 20). However, the relative efficiency of the two functions could not be determined from these correlation coefficients because of the varying degrees of correlation among the X variates associated with the main effects and their interactions. Next, the square root and quadratic functions of a single variable were compared by calculating the R^2 of each from the equation[1]:

$$R^2 = \frac{r_{Y1}^2 + r_{Y2}^2 - 2r_{Y1}r_{Y2}r_{12}}{1 - r_{12}^2}$$

where r_{Y1}, r_{Y2} and r_{12} are the linear correlation coefficients between Y and X_1, Y and X_2 and X_1 and X_2, respectively. Where variates for $X^{\frac{1}{2}}$, X and X^2 were included for a single variable, the R^2 were calculated for both functions, considering that $X_1 = X^{\frac{1}{2}}$ and $X_2 = X$ in the square root function, $X_1 = X$ and

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[1]This test was suggested by Dr. E. H. Jebe of the Statistics Department, Iowa State College.

Table 19. The X variates included in the preliminary calculations of the sums of squares and cross products and the correlation coefficients for each of the dependent (Y) variates

Variable	X variate[a]	X variates included with the following Y variates[b]		
		Δ % P (Y_1), Δ yield (Y_3)	%P (Y_2)	Yield (Y_4)
N fertilizer level (lbs. N/A.)	$N^{\frac{1}{2}}$	X_1[c]	X_1	X_1
	N	X_2	X_2	X_2
	N^2	X_3	X_3	X_3
P fertilizer level (lbs. P_2O_5/A.)	$P^{\frac{1}{2}}$	X_4	X_4	X_4
	P	X_5	X_5	X_5
	P^2	X_6	X_6	X_6
N x P fertilizer interaction	$N^{\frac{1}{2}}P^{\frac{1}{2}}$	X_7	X_7	X_7
	NP	X_8	X_8	X_8
Soil test P level in the plow-layer (lbs. P/A.)	$P_s^{\frac{1}{2}}$	X_9	X_9	X_9
	P_s	X_{10}	X_{10}	X_{10}
	P_s^2	X_{11}	X_{11}	X_{11}

[a]Hereinafter, these symbols will be used to designate the variates in the regression models and analyses. The value of the interaction variate is the product of the indicated powers of the two variates.

[b]The dependent variates (estimated Y's) in the regression models and analyses are designated hereinafter as: Δ%P (Y_1) = change in percent P in the corn leaf, %P (Y_2) = percent P in the corn leaf, Δ yield (Y_3) = change in corn yield in bushels per acre and Yield (Y_4) = corn yield in bushels per acre.

[c]This numbering of the X_i variates was used only in the preliminary calculations.

Table 19. (Continued)

Variable	X variate[a]	X variates included with the following Y variates[b]		
		Δ%P (Y_1), Δyield (Y_3)	%P (Y_2)	Yield (Y_4)
Soil test P level in the subsoil (lbs. P/A.)	$P_{sub.}$	X_{12}	X_{12}	X_{12}
Method of P application (0 = BPU, 1 = BDI)	$P_{meth.}$	X_{13}	X_{13}	X_{13}
Stand level (thousands of stalks/A.)	S	X_{14}	X_{14}	X_{14}
	S^2	X_{15}	X_{15}	X_{15}
N fertilizer x soil test P interaction	$N^{\frac{1}{2}} \times P_s^{\frac{1}{2}}$	X_{16}	X_{16}	X_{16}
	$N \times P_s^{\frac{1}{2}}$	X_{17}	X_{17}	X_{17}
	$N \times P_s$	X_{18}	X_{18}	X_{18}
P fertilizer x soil test P interaction	$P^{\frac{1}{2}} \times P_s^{\frac{1}{2}}$	X_{19}	X_{19}	X_{19}
	$P \times P_s^{\frac{1}{2}}$	X_{20}	X_{20}	X_{20}
Percent N in the leaf at the given level of N and P fertilizer	$\%N^{\frac{1}{2}}$			X_{21}
	%N		X_{21}	X_{22}
	$\%N^2$		X_{22}	X_{23}
Percent P in the leaf at the given level of N and P fertilizer	$\%P^{\frac{1}{2}}$			X_{24}
	%P			X_{25}
	$\%P^2$			X_{26}
Percent N x percent P interaction	$\%N^{\frac{1}{2}} \times \%P^{\frac{1}{2}}$			X_{27}
	%N x %P			X_{28}
Check percent N (%N in the leaf at N_0P_0)	Ck.%N	X_{21}	X_{23}	
	Ck.$\%N^2$	X_{22}	X_{24}	

Table 19. (Continued)

Variable	X variate[a]	X variates included with the following Y variates[b]	
		Δ %P (Y_1), Δ yield (Y_3)	%P (Y_2) Yield (Y_4)
Check percent P (%P in the leaf at N_0P_0)	Ck.%$P^{\frac{1}{2}}$	X_{23}	
	Ck.%P	X_{24}	
	Ck.%P^2	X_{25}	
Check percent N x Check percent P interaction	Ck.%N x Ck.%$P^{\frac{1}{2}}$	X_{26}	
	Ck.%N x Ck.%P	X_{27}	
N x Check percent N interaction	$N^{\frac{1}{2}}$ x Ck.%N		X_{25}
	N x Ck.%N	X_{28}	X_{26}
P x Check percent N interaction	$P^{\frac{1}{2}}$ x Ck.%N		X_{27}
	P x Ck.%N	X_{29}	X_{28}
N x Check percent P interaction	N x Ck.%P	X_{30}	
P x Check percent P interaction	P x Ck.%P	X_{31}	
Check percent N x soil test P interaction	Ck.%N x $P_s^{\frac{1}{2}}$	X_{32}	
Check yield, yield at N_0P_0 (bu./A.)	Ck. yield	X_{33}	

$X_2 = X^2$ in the quadratic function and $r_{12} = r_{X^{\frac{1}{2}}X}$ and r_{XX^2} in the square root and quadratic functions, respectively.

The R^2 of the square root and quadratic functions of the single variables, the r^2 between each of the dependent variates and the individual X variates and the correlation coef-

Table 20. Linear correlation coefficients (r) between the dependent (Y) variates and the X variates

X variate	r between X variate and:			
	$\Delta\%P$ $(Y_1)^a$	$\%P$ $(Y_2)^b$	Δyield $(Y_3)^a$	Yield $(Y_4)^b$
$N^{\frac{1}{2}}$	.100	.117	.362	.222
N	.148	.140	.397	.212
N^2	.169	.140	.378	.171
$P^{\frac{1}{2}}$	.547	.324	.373	.255
P	.569	.317	.425	.247
P^2	.525	.273	.446	.212
$N^{\frac{1}{2}}P^{\frac{1}{2}}$	.519	.298	.601	.318
NP	.487	.276	.579	.284
$P_s^{\frac{1}{2}}$	-.248	.292	-.184	.172
P_s	-.217	.253	-.162	.146
P_s^2	-.150	.162	-.127	.106
$P_{sub.}$	-.213	.238	-.212	.162
$P_{meth.}$	-.102	.092	-.145	.157
S	.044	-.014	.106	.256
S^2	.041	-.031	.106	.227

[a]Number of observations = 474. Values of r larger than 0.091 and .119 are significant at the 5% and 1% levels, respectively.

[b]Number of observations = 574. Values of r larger than 0.084 and 0.110 are significant at the 5% and 1% levels, respectively.

Table 20. (Continued)

X variate	r between X variate and:			
	Δ%P (Y_1)	%P (Y_2)	Δyield (Y_3)	Yield (Y_4)
$N^{\frac{1}{2}} \times P_s^{\frac{1}{2}}$	.010	.211	.258	.279
$N \times P_s^{\frac{1}{2}}$	.062	.221	.313	.266
$N \times P_s$	.009	.241	.237	.266
$P^{\frac{1}{2}} \times P_s^{\frac{1}{2}}$	.297	.356	.177	.251
$P \times P_s^{\frac{1}{2}}$	.339	.353	.237	.246
$\%N^{\frac{1}{2}}$				.524
%N		.555		.514
$\%N^2$		.547		.490
$\%P^{\frac{1}{2}}$				.607
%P				.587
$\%P^2$				.540
$\%N^{\frac{1}{2}} \times \%P^{\frac{1}{2}}$				.636
%N x %P				.606
Ck.%N	-.192	.493	-.265	
$Ck.\%N^2$	-.190	.490	-.260	
$Ck.\%P^{\frac{1}{2}}$	-.406		-.432	
Ck.%P	-.400		-.422	
$Ck.\%P^2$	-.378		-.394	
$Ck.\%N \times Ck.\%P^{\frac{1}{2}}$	-.306		-.364	
Ck.%N x Ck.%P	-.341		-.388	
$N^{\frac{1}{2}}$ x Ck.%N		.186		

Table 20. (Continued)

X variate	r between X variate and:			
	Δ%P (Y_1)	%P (Y_2)	Δyield (Y_3)	Yield (Y_4)
N x Ck.%N	.090	.199	.310	
$P^{\frac{1}{2}}$ x Ck.%N		.406		
P x Ck.%N	.503	.393	.343	
N x Ck.%P	.029		.267	
P x Ck.%P	.388		.226	
Ck.%N x $P_s^{\frac{1}{2}}$	-.302		-.268	
Ck. yield	-.235		-.379	

ficients (r) between the X variates of the curvilinear functions are given in Table 21. There was little difference between the square root and quadratic functions of the variables except that the R^2 of the square root function of the soil test P variable was about 1.5%[1] higher than that of the quadratic function for all Y variates. However, the influence of the interactions with the other variables is not included in these comparisons since the linear correlations were calculated over all levels of the other variables. In this respect, these comparisons are different from the preliminary fitting of a single nutrient variable to five different func-

[1]The difference in the R^2 of two functions or models is expressed as the percent of the total sum of squares due to regression. This difference, therefore, is the absolute difference in percent between two R^2, not a percentage change of one R^2 in relation to the second R^2.

Table 21. Coefficients of multiple determination (R^2) of the dependent variates (Y) on the single-variable square root and quadratic functions, coefficients of determination (r^2) of the Y variates on the individual X variates and correlation coefficients (r) between the X variates

Y variate	X variates	r_{12}	r_{Y1}^2	r_{Y2}^2	R^2
Δ%P (Y_1)	$N^{\frac{1}{2}}$, N	.9428	.0101	.0218	.0353
	N, N^2	.9227	.0218	.0286	.0291
	$P^{\frac{1}{2}}$, P	.9559	.2994	.3234	.3236
	P, P^2	.9255	.3234	.2759	.3234
	$P_s^{\frac{1}{2}}$, P_s	.9784	.0615	.0469	.0774
	P_s, P_s^2	.9183	.0469	.0225	.0621
	Ck.%$P^{\frac{1}{2}}$, Ck.%P	.9958	.1652	.1600	.1679
	Ck.%P, Ck.%P^2	.9851	.1600	.1431	.1686
	Ck.%N, Ck.%N^2	.9953	.0369	.0361	.0370
	S, S^2	.9929	.0020	.0017	.0024
%P (Y_2)	$N^{\frac{1}{2}}$, N	.9508	.0136	.0197	.0227
	N, N^2	.9200	.0197	.0196	.0205
	$P^{\frac{1}{2}}$, P	.9646	.1047	.1004	.1050
	P, P^2	.9273	.1004	.0746	.1035
	$P_s^{\frac{1}{2}}$, P_s	.9780	.0853	.0640	.1103
	P_s, P_s^2	.9176	.0640	.0261	.0958
	%N, %N^2	.9937	.3081	.2989	.3099
	Ck.%N, Ck.%N^2	.9953	.2428	.2397	.2429
	S, S^2	.9929	.0002	.0010	.0022

Table 21. (Continued)

Y variate	X variates	r_{12}	r_{Y1}^2	r_{Y2}^2	R^2
Δyield (Y_3)	$N^{\frac{1}{2}}$, N	.9428	.1312	.1580	.1594
	N, N^2	.9227	.1580	.1431	.1589
	$P^{\frac{1}{2}}$, P	.9559	.1392	.1802	.1927
	P, P^2	.9255	.1802	.1989	.1999
	$P_s^{\frac{1}{2}}$, P_s	.9784	.0337	.0262	.0411
	P_s, P_s^2	.9183	.0262	.0163	.0291
	Ck.%$P^{\frac{1}{2}}$, Ck.%P	.9958	.1863	.1777	.1945
	Ck.%P, Ck.%P^2	.9851	.1777	.1556	.1924
	Ck.%N, Ck.%N^2	.9953	.0703	.0677	.0718
	S, S^2	.9929	.0113	.0113	.0114
Yield (Y_4)	$N^{\frac{1}{2}}$, N	.9508	.0491	.0447	.0492
	N, N^2	.9200	.0447	.0294	.0473
	$P^{\frac{1}{2}}$, P	.9646	.0650	.0612	.0650
	P, P^2	.9273	.0612	.0449	.0635
	$P_s^{\frac{1}{2}}$, P_s	.9780	.0295	.0213	.0414
	P_s, P_s^2	.9176	.0213	.0113	.0259
	%$N^{\frac{1}{2}}$, %N	.9976	.2750	.2639	.2965
	%N, %N^2	.9937	.2639	.2402	.2970
	%$P^{\frac{1}{2}}$, %P	.9961	.3682	.3443	.4087
	%P, %P^2	.9881	.3443	.2917	.4108
	S, S^2	.9929	.0656	.0517	.1166

tions by Heady et al. (39) since they used the data for one variable at successive fixed levels of the other nutrient variable.

The relative difference between a two-term curvilinear function of a variable and its single-term linear or transformed variate, disregarding interaction effects, was approximated by comparing the R^2 of the square root or quadratic function with the r^2 of the linear, square root or squared term (Table 21). The curvilinear effects of N and P fertilizer appeared to be small on all Y variates except the change in yield (Y_3) where the curvilinear effect of P fertilizer appeared to be appreciable. Soil test P had an appreciable curvilinear effect on all Y variates. The percent N and percent P in the leaf appeared to have a considerable curvilinear effect on the yield (Y_4). The Check percent P appeared to have some curvilinear effect on change in percent P (Y_1) and a considerable effect on change in yield (Y_3). The Check percent N had little curvilinear effect on the three Y variates with which it was associated. Stand level had a large curvilinear effect on yield (Y_4) but little effect on the other Y variates.

However, the unconfounded curvilinear effects of the various variables may be different from these comparisons since the interaction effects are not considered and these estimated curvilinear effects are not independent of the line-

ar and curvilinear effects of the other variables. An imperfection of the data in this study for predicting curvilinear effects in the population is the unequal frequency of the observations throughout the entire range. Since the deviations from linearity appeared to occur primarily at the extremes, the effect of the fewer observations at the extremes may be minimized by the larger number of observations near the mean.

The square root and quadratic functions can be compared most accurately by determining the R^2 of the complete regression equation containing the square root functions and of the one containing quadratic functions. With 3 to 5 variables present whose effects may be curvilinear on the Y variates, the regression model could include all square root functions, all quadratic functions or any combination of the two functions (mixed model). Testing all possible combinations would be time-consuming and costly and might show only small differences unless the curvilinear effects were marked. However, the objective of including extra terms in the preliminary calculations in this study was to make at least some comparisons between the two types of functions in the complete regression equations.

In the regression of the yield (Y_4) on selected variables, four variables and associated interaction terms were included in one model (designated as Square Root Model) as square root functions and in the other model (Quadratic Model) as quad-

ratic functions. The soil test P variable was included as a square root function in both models on the basis of the previous comparisons (Table 21). The stand level variable was included as a quadratic function in both models since a square root variate was not included in the preliminary calculations. In addition, all squared X variates were eliminated from the Quadratic Model (Linear Model) in order to compare the precision of the curvilinear and linear functions. The models for the three regressions are given in Table 22.

There was no difference between the R^2 of the regression equation containing the square root and the one containing the quadratic functions of the four variables. The Linear Model, without the squared terms, accounted for only 4% less of the variations in yield than the curvilinear models. Little difference between the square root and quadratic functions would be expected since the gain in precision was small due to fitting the data to curvilinear functions.

The comparison between the Square Root and Quadratic Models was complicated by computational difficulties. Because of the high correlations (the r_{12} in Table 21) between the two terms of the curvilinear functions, the calculated inverse matrices of both models by the IBM 650 Computer were not symmetrical. However, the solution of the inverse matrix for the Quadratic Model was much more reasonable than that for the Square Root Model. For example, in the Square Root Model, some of the c_{ij} values in half of the inverse matrix were half or double

Table 22. Regression models used to compare the efficiency of the square root and quadratic functions and the curvilinear and linear functions

X_i variate, i =	Regression of yield (Y_4) on the following X variates for the: Square Root Model	Quadratic Model	Linear Model
1	$N^{\frac{1}{2}}$	N	N
2	N	N^2	-
3	$P^{\frac{1}{2}}$	P	P
4	P	P^2	-
5	$N^{\frac{1}{2}}P^{\frac{1}{2}}$	NP	NP
6	$P_s^{\frac{1}{2}}$	$P_s^{\frac{1}{2}}$	$P_s^{\frac{1}{2}}$
7	P_s	P_s	-
8	$P_{sub.}$	$P_{sub.}$	$P_{sub.}$
9	$P_{meth.}$	$P_{meth.}$	$P_{meth.}$
10	S	S	S
11	S^2	S^2	-
12	$N^{\frac{1}{2}} \times P_s^{\frac{1}{2}}$	$N \times P_s^{\frac{1}{2}}$	$N \times P_s^{\frac{1}{2}}$
13	$P^{\frac{1}{2}} \times P_s^{\frac{1}{2}}$	$P \times P_s^{\frac{1}{2}}$	$P \times P_s^{\frac{1}{2}}$
14	$\%N^{\frac{1}{2}}$	$\%N$	$\%N$
15	$\%N$	$\%N^2$	-
16	$\%P^{\frac{1}{2}}$	$\%P$	$\%P$
17	$\%P$	$\%P^2$	-
18	$\%N^{\frac{1}{2}} \times \%P^{\frac{1}{2}}$	$\%N \times \%P$	$\%N \times \%P$
R	0.7886	0.7890	0.7642
R^2	0.6219	0.6225	0.5839

the values in the other half and the partial regression coefficients calculated from the matrix in two different ways varied up to ± 30%. In the Quadratic Model, the c_{ij} values in the two halves of the matrix did not vary more than one in the fourth significant digit and the partial regression coefficients did not vary more than four in the fifth significant digit of the eight digits carried in the IBM 650 output.

A high correlation between two separate variables in a regression analysis usually results in little gain by including both in the regression equation. However, the high correlation between terms of the square root or quadratic function is independent of the degree of deviation of the variable from linearity and is a function of the range in the observations of the variable. The variables with the highest correlations between the terms, such as the stand level and Check percent N in the leaf (Table 21), had a narrow range of values with the highest ones being somewhat more than twice the lowest values. Since the square roots of these values had a narrower range than the squares of the values, the correlation coefficients were somewhat higher between the values and their square roots than between the values and the squares.

The failure to obtain a symmetrical inverse matrix in the Square Root Model lies in the limitation of the particular program used with the IBM 650 Computer since this program for

the matrix inversion carries only eight digits in addition to the two digits required for the floating decimal system. If more digits could be carried in the operations, less difficulty would be encountered with correlation coefficients between terms as high as the ones in this study. For example, a reasonable inverse matrix was obtained in the Quadratic Model whose three highest correlation coefficients were 0.9937, 0.9881 and 0.9929. The inverse matrix was not symmetrical in the Square Root Model whose three highest ones were 0.9976, 0.9961 and 0.9929. In future regression analyses of this type, coding the variables to extend their range and to reduce the correlation between the terms also should eliminate this difficulty. Increasing the observed range of the variables, when feasible, also will decrease the correlation between the terms of the square root or quadratic functions.

From this preliminary study of the square root and quadratic functions, the square root function for the soil test P variable and the quadratic functions for the other variables whose effects were believed to be curvilinear were selected for the regression models of the other dependent variates. However, much more research needs to be done on the selection of the curvilinear function for multiple curvilinear regression analyses, particularly if interaction terms with curvilinear components are included.

2. Change in the percent P

For the regression of the change in the percent P in the corn leaf due to N and P fertilization (Y_1)[1], the regression statistics of five multiple regression models were determined (Table 23). The multiple curvilinear regression model (designated Curvilinear Model) included 22 X variates. A linear multiple regression model (Linear Model) with 17 X variates was included to determine the value of the five curvilinear functions in estimating Y_1.

The soil test P variates and leaf P variates were compared for estimating Y_1 in three multiple curvilinear regression models. In one comparison, the five variates associated with the soil test P level in the surface and 12 common variates (Soil Test P Model) were compared with five variates associated with the Check percent P level and the 12 common variates (Leaf P Model). In the third model (Leaf P Reduced Model), the $P_{sub.}$ variate was deleted from the Leaf P Model so that six variates associated with the soil test P level in the plow-layer and subsoil and 11 common variates could be compared with the five variates associated with the Check percent P level and 11 common variates. The variates associated with the Soil Test P and Leaf P Models are given in Table 23.

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[1]Hereinafter, the symbols for the dependent (Y) variates and X variates as listed in Table 19 will be used when specific variates are being discussed.

Table 23. Multiple regression statistics for the regression models of the change in percent P in the corn leaf (Y_1) on selected X variates

Model	Variate	Equation[a] $\hat{Y}_1 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Curvilinear		-123.8[c]			
	N	$+0.8026\ X_1$	0.1560	5.14	**
	N^2	$-0.001678\ X_2$	0.000368	4.56	**
	P	$+1.182\ X_3$	0.1841	6.42	**
	P^2	$-0.003396\ X_4$	0.000650	5.22	**
	NP	$+0.002202\ X_5$	0.000516	4.27	**
	$P_s^{\frac{1}{2}}$	$+51.75\ X_6$	16.00	3.23	**
	P_s	$-1.937\ X_7$	2.008	0.96	0.34
	$P_{sub.}$	$-0.04670\ X_8$	0.1411	0.33	>0.50
	$P_{meth.}$	$-2.694\ X_9$	2.258	1.19	0.24
	S	$+0.1576\ X_{10}$	0.4708	0.34	>0.50
	$N \times P_s^{\frac{1}{2}}$	$+0.07031\ X_{11}$	0.04318	1.63	0.11
	$P \times P_s^{\frac{1}{2}}$	$-0.2534\ X_{12}$	0.05120	4.95	**
	Ck.%N	$+66.23\ X_{13}$	30.09	2.20	*
	Ck.%N^2	$+12.32\ X_{14}$	7.881	1.56	0.12
	Ck.%P	$-104.9\ X_{15}$	187.5	0.56	>0.50
	Ck.%P^2	$+2342.8\ X_{16}$	486.2	4.82	**

[a]Values of a, b_i and $s(b_i)$: x 10^3.

[b]Significance probability level.

[c]This is a, the constant in the regression equation.

Table 23. (Continued)

Model	Variate	Equation[a] $\hat{Y}_1 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Curvi-linear					
	Ck.%N x Ck.%P	$-415.2\ X_{17}$	106.2	3.91	**
	N x Ck.%N	$-0.1484\ X_{18}$	0.05916	2.51	*
	P x Ck.%N	$+0.2410\ X_{19}$	0.07692	3.13	**
	N x Ck.%P	$-1.412\ X_{20}$	0.6063	2.33	*
	P x Ck.%P	$-2.531\ X_{21}$	0.7424	3.41	**
	Ck.%N x $P_s^{\frac{1}{2}}$	$-15.96\ X_{22}$	4.603	3.47	**
Linear		-72.0[c]			
	N	$+0.4666\ X_1$	0.1481	3.15	**
	P	$+0.7427\ X_3$	0.1717	4.33	**
	NP	$+0.001796\ X_5$	0.000545	3.30	**
	$P_s^{\frac{1}{2}}$	$+38.99\ X_6$	12.23	3.27	**
	$P_{sub.}$	$+0.03600\ X_8$	0.1488	0.24	>0.50
	$P_{meth.}$	$-2.942\ X_9$	2.397	1.23	0.22
	S	$+0.05404\ X_{10}$	0.4941	0.11	>0.50
	N x $P_s^{\frac{1}{2}}$	$+0.06903\ X_{11}$	0.04576	1.51	0.14
	P x $P_s^{\frac{1}{2}}$	$-0.2475\ X_{12}$	0.05416	4.57	**
	Ck.%N	$+35.88\ X_{13}$	14.10	2.54	**
	Ck.%P	$+43.96\ X_{15}$	149.6	0.29	>0.50
	Ck.%N x Ck.%P	$-39.52\ X_{17}$	51.18	0.77	0.44
	N x Ck.%N	$-0.1275\ X_{18}$	0.06093	2.09	*
	P x Ck.%N	$+0.2338\ X_{19}$	0.08172	2.86	**

Table 23. (Continued)

Model	Variate	Equation[a] $\hat{Y}_1 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Linear					
	N x Ck.%P	$-1.333\ X_{20}$	0.6397	2.08	*
	P x Ck.%P	$-2.229\ X_{21}$	0.7896	2.82	**
	Ck.%N x $P_s^{\frac{1}{2}}$	$-14.35\ X_{22}$	4.702	3.05	**
Soil Test P		-52.4[c]			
	N	$+0.5855\ X_1$	0.1653	3.54	**
	N^2	$-0.001803\ X_2$	0.000396	4.55	**
	P	$+1.125\ X_3$	0.1986	5.66	**
	P^2	$-0.002980\ X_4$	0.000701	4.25	**
	NP	$+0.002649\ X_5$	0.000549	4.82	**
	$P_s^{\frac{1}{2}}$	$+14.86\ X_6$	15.06	0.99	0.33
	P_s	$+3.741\ X_7$	2.021	1.85	0.07
	$P_{sub.}$	$-0.2815\ X_8$	0.1449	1.94	*
	$P_{meth.}$	$-4.799\ X_9$	2.416	1.99	*
	S	$+0.3174\ X_{10}$	0.5070	0.63	>0.50
	N x $P_s^{\frac{1}{2}}$	$+0.02237\ X_{11}$	0.03951	0.57	>0.50
	P x $P_s^{\frac{1}{2}}$	$-0.3675\ X_{12}$	0.04440	8.28	**
	Ck.%N	$+33.15\ X_{13}$	29.30	1.13	0.26
	Ck.%N^2	$-3.463\ X_{14}$	5.534	0.63	>0.50
	N x Ck.%N	$-0.1642\ X_{18}$	0.05486	2.99	**
	P x Ck.%N	$+0.0906\ X_{19}$	0.06503	1.39	0.17
	Ck.%N x $P_s^{\frac{1}{2}}$	$-10.97\ X_{22}$	4.591	2.39	*

Table 23. (Continued)

Model	Variate	Equation[a] $\hat{Y}_1 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Leaf P		-52.9[c]			
	N	+0.8258 X_1	0.1582	5.22	**
	N^2	-0.001735 X_2	0.000380	4.57	**
	P	+0.9078 X_3	0.1833	4.95	**
	P^2	-0.003188 X_4	0.000673	4.74	**
	NP	+0.002310 X_5	0.000530	4.36	**
	$P_{sub.}$	-0.06247 X_8	0.1484	0.42	>0.50
	$P_{meth.}$	-0.1727 X_9	2.221	0.08	>0.50
	S	+0.009019 X_{10}	0.4820	0.02	>0.50
	Ck.%N	+31.55 X_{13}	27.98	1.13	0.26
	Ck.%N^2	+15.46 X_{14}	8.048	1.92	0.06
	Ck.%P	+116.8 X_{15}	171.2	0.68	0.50
	Ck.%P^2	+2279.7 X_{16}	484.4	4.71	**
	Ck.%N x Ck.%P	-473.7 X_{17}	108.6	4.36	**
	N x Ck.%N	-0.1901 X_{18}	0.06015	3.16	**
	P x Ck.%N	+0.3524 X_{19}	0.07672	4.59	**
	N x Ck.%P	-0.5808 X_{20}	0.5287	1.10	0.27
	P x Ck.%P	-4.778 X_{21}	0.6133	7.79	**

The $P_{sub.}$ variate was considered a common variate in the comparison between the Soil Test P and Leaf P Models. If only the soil test P level in the plow-layer is available and the level in the subsoil must be estimated from the soil type mean, the $P_{sub.}$ variate should be considered a common variate when comparing soil test and leaf analysis methods for estimating Y_1. For a more precise comparison of the soil test and leaf analysis methods, the $P_{sub.}$ variate should not be included with the leaf P variates. Therefore, this variate was deleted from the Leaf P Model and the regression statistics of the remaining terms in the Leaf P Reduced Model recalculated according to the procedure given by Snedecor (74).

Since soil test N variates were not included in this study, the Check percent N in the leaf was assumed to be an estimate of the N availability in the soil and was included with the common variates in the comparisons between the soil test P and leaf P levels. If the effect of the interaction between the soil test N and soil test P is much different from the effect of the one between the Check percent N in the leaf and soil test P, the comparisons between the soil test P and leaf P for predicting Y_1 may be biased.

The regression statistics of all the models except the Leaf P Reduced Model are given in Table 23 and include the regression equation, the partial regression coefficients, the standard errors of each regression coefficient, the t values

and the significance probability levels of the individual t values. The Leaf P Reduced Model was omitted since its regression statistics were almost identical to those of the Leaf P Model.

The multiple regression equations were calculated from:

$$\hat{Y} = \bar{Y} + \sum_{i=1}^{r} b_i (X_i - \bar{X}_i) = a + \sum_{i=1}^{r} b_i X_i ,$$

where a (the constant) = $\bar{Y} - \sum b_i X_i$ and the b_i, partial regression coefficients, were obtained from the inverse matrix computed by the IBM 650 Computer from the input matrix of the sums of squares and cross products of the X_i and Y_i variates, corrected to the means.

The variance (s^2) of the residual error, the sum of squares of the variations in Y not accounted for by the regression of Y on the X_i variates, was obtained from:

$$s^2 = \frac{SSE}{n-r-1} ,$$

where SSE is the residual error sum of squares obtained from the IBM 650 output and n-r-1 is the degrees of freedom associated with the residual error where n is the total number of observations and r is the number of X variates in the regression model.

The standard errors of the partial regression coefficients, $s(b_i)$, were calculated from:

$$s(b_i) = (c_{ii} s^2)^{\frac{1}{2}} ,$$

where the c_{ii} values, Gaussian multipliers, were obtained from the inverse matrix.

The null hypothesis that each of the partial regression coefficients equals zero, H_0: $\beta_i = 0$, was tested by:

$$t = \frac{|b_i|}{s(b_i)} \quad ,$$

where $|b_i|$ is the absolute value of the partial regression coefficient and the calculated t was compared with tabular t to determine the probability of obtaining as large or larger value of t by chance, given the null hypothesis. However, no significance probability level was established for acceptance of this hypothesis and deletion of the variate from the equation whose t value exceeded the established significance level. It appears to be logical to retain the variate in the regression equation if its partial regression coefficient is equal to or greater than its standard error. In this study the probability of obtaining a t value equal to one by chance is 0.32 or about one-third of the time.

The fraction of the variations in the dependent variate explained by regression on the X variates (R^2) of each regression equation was calculated from:

$$R^2 = \frac{SSR}{S_y^{\,2}} = \frac{S_y^{\,2} - SSE}{S_y^{\,2}} \quad ,$$

where SSR is the sum of squares due to regression.

The null hypothesis that all $\beta_i = 0$ was tested by:

$$F = \frac{SSR}{rs^2} ,$$

with the calculated F compared with tabular F at r and n-r-1 degrees of freedom. The sum of squares due to regression was highly significant in all five models (Table 24) with the R^2 of the individual models varying from 0.556 to 0.629.

Table 24. Analyses of variance for the multiple regression models of the change in percent P in the corn leaf (Y_1) on selected X variates

Model	Source of variation	d.f.	S.S.	M.S.	F	R	R^2
Curvi-linear	Regression	22	.33727	.015330	35**	.7932	.6291
	Error	451	.19883	.000441			
Linear	Regression	17	.30724	.018073	36**	.7570	.5731
	Error	456	.22886	.000502			
Soil Test P	Regression	17	.29831	.017548	34**	.7460	.5564
	Error	456	.23779	.000521			
Leaf P	Regression	17	.31850	.018735	39**	.7708	.5941
	Error	456	.21760	.000477			
Leaf P Reduced	Regression	16	.31841	.019901	42**	.7707	.5939
	Error	457	.21769	.000476			

The significance of the reduction in the residual error by including additional variates in the multiple regression equation also can be tested. If the reduction in the error sum of squares due to the first k variates is called SSR_k, the added reduction due to the last (r - k) variates is

$SSR - SSR_k$. The null hypothesis, H_0: $\beta_{r-k} = 0$, is tested by:

$$F = \frac{SSR-SSR_k}{s^2(r-k)} ,$$

with the calculated F compared with tabular F at r-k and n-r-1 degrees of freedom.

The added reduction in the residual error by including the five curvilinear variates (squared terms) was highly significant (Table 25) and they gave an increase of 5.6% in the R^2 of the Curvilinear Model over that of the Linear Model. The added reduction of the five leaf P variates also was highly significant, increasing the R^2 of the Curvilinear Model over the Soil Test P Model by 7.3%. Addition of the 5 or 6 soil test P variates gave a highly significant reduction in the residual error with the R^2 of the Curvilinear Model being 3.5% higher than that of either the Leaf P or Leaf P Reduced Models. The R^2 of the Leaf P Models (0.594) and of the Soil Test P Model (0.556) indicate that Y_1 can be estimated with somewhat more precision from the leaf P composition than from the soil test P data although the highest precision occurs when both are included in the prediction equation.

The deletion of the $P_{sub.}$ variate had no effect on the R^2 of the Leaf P model but did have a significant effect on the R^2 of the Soil Test P Model (Table 25). However, the R^2 of the Soil Test P Model was only reduced from 0.556 to 0.553 by the deletion of this variate. When only one variate is

Table 25. Analyses of variance of the reduction in residual error due to curvilinear, leaf P and soil test P variates in the regressions of the change in percent P in the corn leaf (Y_1) on selected X variates

Models	Source of variation	d.f.	S.S.	M.S.	F
Curvilinear vs. Linear	Regression on 17 variates	17	.307241		
	Added reduction by 5 curvilinear variates	5	.030026	.006005	13.6**
	Error	451	.198832	.000441	
Curvilinear vs. Soil Test P	Regression on 17 variates	17	.298309		
	Added reduction by 5 leaf P variates	5	.038958	.007792	17.6**
	Error	451	.198832	.000441	
Curvilinear vs. Leaf P	Regression on 17 variates	17	.318500		
	Added reduction by 5 soil test P variates	5	.018767	.003753	8.5**
	Error	451	.198832	.000441	
Curvilinear vs. Leaf P Reduced	Regression on 16 variates	16	.318413		
	Added reduction by 6 soil test P variates	6	.018854	.003142	7.1**
	Error	451	.198832	.000441	
Leaf P vs. Leaf P Reduced	Regression on 16 variates	16	.318413		
	Added reduction by $P_{sub.}$ variate	1	.000087	.000087	0.18
	Error	456	.217599	.000477	
Soil Test P vs. Soil Test P Reduced	Regression on 16 variates	16	.296340		
	Added reduction by $P_{sub.}$ variate	1	.001969	.001969	3.78*
	Error	456	.237790	.000521	

deleted or added, the F test of the significance in Table 25 is the same as the t test of the significance of the partial regression coefficient in Table 23. With only one degree of freedom, $t^2 = F$, as is illustrated in the tests of significance of the addition of the $P_{sub.}$ variate; the t and F values for this variate were 0.42 and 0.18, respectively, in the Leaf P Model and were 1.94 and 3.78, respectively, in the Soil Test P Model.

Since the highest linear correlation coefficient was between Y_1 and the P variate, whose r^2 was 0.325 (Table 26), including other variates in the multiple regression equations gave a large gain in the precision in estimating Y_1.

The significance levels of more than half of the partial regression coefficients were similar among the four models but those of some of the others varied widely (Table 23). Since there is little interest in the Linear Model except as a method of testing the value of the curvilinear functions, it will not be discussed further. If the 32% significance level is established as the level of acceptance of the null hypothesis that the population regression coefficients are zero, the variates whose t values of their partial regression coefficients are less than one may be deleted from the regression equation. However, an exception to this procedure should be followed for the linear term in the quadratic function, particularly if it is a factor in some of the interac-

Table 26. Linear correlation coefficients (r) between the X variates associated with both the change in percent P (Y_1) and change in yield (Y_3) and between the X variates and Y_1 and Y_3

X variate	X variate								
	N^2	P	P^2	NP	$P_s^{\frac{1}{2}}$	P_s	$P_{sub.}$	$P_{meth.}$	S
N	.92[a]	.04	.21	.68	.06	.05	-.05	-.16	.00
N^2	1.00	.17	.32	.72	.02	.01	-.09	-.17	.01
P		1.00	.93	.64	-.04	-.04	-.17	-.07	.02
P^2			1.00	.72	-.05	-.03	-.17	-.10	.04
$NP_{\frac{1}{2}}$				1.00	.03	.02	-.12	-.16	.02
$P_s^{\frac{1}{2}}$					1.00	.98	.10	-.14	-.03
P_s						1.00	.08	-.14	-.04
$P_{sub.}$							1.00	.23	.05
$S_{meth.}$								1.00	-.10
									1.00

	X variate							
	N x $P_s^{\frac{1}{2}}$	P x $P_s^{\frac{1}{2}}$	Ck. %N	Ck. $\%N^2$	Ck. %P	Ck. $\%P^2$	Ck.%N x Ck.%P	N x Ck.%N
N	.91	.07	-.11	-.11	-.01	-.02	-.07	.97
N^2	.83	.18	-.09	-.09	-.01	-.01	-.05	.88
P	.03	.88	-.04	-.04	-.09	-.08	-.07	.03
P^2	.18	.80	-.07	-.07	-.10	-.09	-.09	.19
$NP_{\frac{1}{2}}$	.63	.59	-.08	-.07	-.06	-.06	-.08	.66
$P_s^{\frac{1}{2}}$	.36	.34	.04	.04	.45	.41	.28	.09
P_s	.34	.33	.01	.00	.39	.36	.23	.07
$P_{sub.}$	-.02	-.12	.20	.19	.36	.38	.33	-.01
$S_{meth.}$	-.18	-.11	.07	.07	.11	.12	.11	-.15
N x $P_s^{\frac{1}{2}}$	-.03	-.02	-.10	-.09	-.04	-.02	-.06	-.03
P x $P_s^{\frac{1}{2}}$	1.00	.17	-.05	-.06	.14	.12	.05	.90
Ck.%N		1.00	.00	.00	.11	.10	.06	.08
Ck.$\%N^2$			1.00	.995	.60	.58	.86	.08
Ck.%P				1.00	.60	.58	.86	.08
Ck.$\%P^2$					1.00	.985	.91	.10
						1.00	.91	.09

[a]Number of observations = 474. Values of r larger than 0.091 and 0.119 are significant at the 5% and 1% levels, respectively.

Table 26. (Continued)

X variate	X variate							
	N x $P_s^{\frac{1}{2}}$	P x $P_s^{\frac{1}{2}}$	Ck. %N	Ck. $\%N^2$	Ck. %P	Ch. $\%P^2$	Ch.%N x Ck. %P	N x Ck.%N
Ck.%N x Ck.%P							1.00	.10
N x Ck.%N								1.00

	X variate					Y variate	
	P x Ck.%N	N x Ck.%P	P x Ck.%P	Ck.%N x $P_s^{\frac{1}{2}}$	Ck. yield	Δ%P (Y_1)	Δyield (Y_3)
N	.01	.95	.02	.02	-.12	.15	.40
N^2	.15	.88	.16	.00	-.12	.17	.38
P	.96	.01	.93	-.05	-.10	.57	.42
P^2	.87	.16	.84	-.06	-.13	.52	.45
NP	.59	.62	.58	.00	-.12	.49	.58
$P_s^{\frac{1}{2}}$	-.02	.17	.10	.87	.29	-.25	-.18
P_s	-.02	.14	.08	.84	.25	-.22	-.16
$P_{sub.}$	-.14	.03	-.09	.17	.29	-.21	-.21
$P_{meth.}$	-.06	-.13	-.04	-.12	.23	-.10	-.14
S	-.01	-.03	-.02	-.05	.19	.04	.11
N x $P_s^{\frac{1}{2}}$	.02	.94	.07	.29	.01	.06	.31
P x $P_s^{\frac{1}{2}}$	.86	.08	.92	.29	.03	.34	.24
Ck.%N	.19	.02	.13	.50	.58	-.19	-.26
$Ck.\%N^2$	.19	.02	.13	.50	.56	-.19	-.26
Ck.%P	.05	.21	.20	.65	.62	-.40	-.42
$Ck.\%P^2$	.05	.19	.20	.62	.57	-.38	-.39
Ck.%N x Ck.%P	.12	.13	.18	.64	.65	-.34	-.39
N x Ck.%N	.05	.96	.05	.13	.02	.09	.31
P x Ck.%N	1.00	.01	.96	.07	.05	.50	.34
N x Ck.%P		1.00	.06	.16	.03	.03	.27
P x Ck.%P			1.00	.15	.08	.39	.23
Ck.%N x $P_s^{\frac{1}{2}}$				1.00	.49	-.30	-.27
Ck. yield					1.00	-.24	-.38

tion terms. If the squared term or any of the interaction terms is significant, the linear variate should be retained in the regression equation although its t value may be less than one.

In all three models of interest, the partial regression coefficients of the N, N^2, P, P^2, NP, P x $P_s^{\frac{1}{2}}$, Ck.%P^2, Ck.%N x Ck.%P, N x Ck.%N, P x Ck.%P and Ck.%N x $P_s^{\frac{1}{2}}$ variates were significant at the 5% level or less. The significance level of the other variates varied considerably among the three models. Many of these whose t values were less than one could be deleted from the equation in which they occurred with little loss in precision in estimating Y_1. However, the linear variate in the curvilinear functions such as the $P_s^{\frac{1}{2}}$ variate in the Soil Test P Model and the Ck.%P variate in the other two models should be retained although their t values were less than one.

The t values of the partial regression coefficients were similar in the Curvilinear and Leaf P Models but those of several variates differed considerably in the Curvilinear and Soil Test P Models. These differences probably are due to the high correlation between the soil test P and leaf P variates (Table 26), both of which indicate the availability of the P in the soil. Thus, the effect of the P availability in the soil on $\hat{Y}_1$ is split over both groups of variates. Deletion of either set of variates, as in the Soil Test P and Leaf P Models, may change considerably the partial regression coefficients of the remaining variates and their significance levels. Since the leaf P variates had a more dominant effect on $\hat{Y}_1$ than the soil test P variates as indicated by their

higher correlations with Y_1, the regression statistics of the Leaf P Model were more similar than those of the Soil Test P Model to the Curvilinear Model.

The direction and rate of change in the dependent variate on increasing level of the X variate is of interest in these regressions. In a single-variable quadratic function, $Y = a + b_1X + b_2X^2$, the signs of the coefficients show the slope and direction of change in Y with X. When the sign of b_2 is positive, the vertex, or point of zero slope when the axis of the parabola is parallel to the y-axis, is the minimum value. This curve shows a decreasing change in Y with X in the half with a negative slope and an increasing change in Y with X in the half with a positive slope. If the sign of b_1 is negative, both negative and positive slopes of the curve may occur with positive values of X; if b_1 is positive, only a positive slope occurs with positive values of X.

When the sign of b_2 is negative, the vertex or zero slope is at the maximum value. This curve shows a decreasing change in Y with X in the half with a positive slope and an increasing change in Y with X in the half with a negative slope. If b_1 is positive, both positive and negative slopes may occur with positive values of X; if b_1 is negative, only negative slopes occur with positive values of X.

In the preliminary investigations, the change in percent P (Y_1) was shown as a single-variable function of various

factors. The Y_1 as a function of the N and P fertilizer level had a positive slope with a decreasing change with level (Figures 9 and 14, Table 6). Therefore, its single-variable function on either N or P fertilizer level should have the form, $Y = a + b_1X - b_2X^2$. The change in percent P due to P fertilizer on soil test P and Check percent P levels had a negative slope with a decreasing change with level (Figures 8 and 10). The change in percent P due to N fertilizer on Check percent N and Check percent P levels also was negative with a decreasing change with level (Figures 14 and 15). These functions should have the form, $Y = a - b_1X + b_2X^2$. However, the change in percent P due to P fertilizer on the Check percent N level (Figure 11) and the change in percent P due to N fertilizer on the soil test P level (Figure 16) had slopes of opposite sign in the absence or presence of the other nutrient. In these cases, the Y_1 was primarily a function of the interactions rather than of the single-variable curvilinear functions.

However, in these multiple regression equations, it is much more difficult to determine the direction and rate of change of the dependent variate by varying one variable and keeping all others constant. Since varying degrees of correlation existed among the variables (Table 26), it was impossible to vary one variable over a wide range and keep the variables constant with which it was correlated. Since inter-

action terms also were included, the variates for the main effects were highly correlated with their interaction terms as well as with the interaction terms of other variates with which they were correlated. In such cases of high correlations among variates, Anderson and Bancroft (1) stated that it is impossible to interpret one partial regression coefficient as the change in Y when its X variate varies while holding the other X_i constant since some of these other X_i may vary also. It may be impractical in some analyses to consider that any of the X_i can be held constant while some other one varies. In these cases, they concluded, the regression equation should be considered as a whole.

In the regression equations containing interaction terms, the influence of one variable on the dependent variate is split into several parts: part is contributed by the regression coefficients of the curvilinear function of the main effect and parts are contributed by the regression coefficients of the interaction variates. Disregarding the correlation with other variables, Anderson and Bancroft (1) stated that the change in $\hat{Y}$ when one variable varies is given by taking the partial derivative of $\hat{Y}$ with respect to that variable. For example, the change in $\hat{Y}_1(z)$ in the Curvilinear Model with respect to Check percent P is given by:

$$z = \frac{\partial \hat{Y}_1}{\partial Ck.\%P} = - b_{15} + 2b_{16}\ Ck.\%P - b_{17}\ Ck.\%N - b_{20}N - b_{21}P\ .$$

Therefore, the change in $\hat{Y}_1$ with respect to Check percent P (the slope at a particular point) varies with the Check percent P, Check percent N, N fertilizer and P fertilizer levels.

The average value of the change in $\hat{Y}_1$ is given by substituting the X_i means (Table 27) into the partial derivative equation:

$$\bar{z} = -104.9 + 2(2343)(.232) - 415.2(2.46) - 1.412(52.6) - 2.531(49.5)$$

$$= -238.7$$

The negative value of $\bar{z}$ (negative slope) shows that the direction of the change in $\hat{Y}_1$ on the Check percent P level is negative, at least at the mean level of the other variates with which it had interactions. Whether the slope is increasing or decreasing is determined by taking the second partial derivative with respect to Check percent P. This was positive which shows that the slope is becoming less negative. Therefore, the slope of $\hat{Y}_1$ on increasing level of Check percent P is negative and decreasing. If an attempt is made to determine the slope by taking the partial derivative of only the Ck.%P and Ck.%P^2 variates, disregarding the interactions, the result would be misleading since the partial derivative is positive for all relevant Check percent P values.

Determining the direction and rate of change of the dependent variates at varying levels of the associated X vari-

Table 27. Ranges and means of the observed values of the variates included in the regression analyses

Variate[a]	Observations associated with Y_1 and Y_3 (n=474)		Observations associated with Y_2 and Y_4 (n=574)	
	Range	Mean	Range	Mean
N_2	0 to 180	52.57	0 to 180	43.41
N^2	0 to 32400	5046.8	0 to 32400	4167.6
P	0 to 160	49.54	0 to 160	40.91
P^2	0 to 25600	3941.4	0 to 25600	3254.7
NP	0 to 25600	2678.3	0 to 25600	2211.7
$P_s^{\frac{1}{2}}$	0.71 to 4.24	1.95	0.71 to 4.24	1.96
P_s	0.5 to 18.0	4.19	0.5 to 18.0	4.22
$P_{sub.}$	0.5 to 30.0	4.30	0.5 to 30.0	4.46
$S_{meth.}$	0 to 1	0.35	0 to 1	0.34
S^2	8.8 to 19.3	12.73	8.8 to 19.3	12.75
$N \times P_s^{\frac{1}{2}}$	77 to 372	--	77 to 372	167.20
$P \times P_s^{\frac{1}{2}}$	0 to 477	104.39	0 to 477	86.20
	0 to 379	95.67	0 to 379	79.00
$\%N_2$	--	--	1.08 to 3.33	2.603
$\%N^2$	--	--	1.17 to 11.09	6.925
$\%P_2$	--	--	0.093 to 0.402	0.2590
$\%P^2$	--	--	0.0086 to 0.1616	0.0695
$\%N \times \%P$	--	--	0.148 to 1.216	0.6847
Ck.%N	1.49 to 3.23	2.462	1.49 to 3.23	2.471
Ck.%N^2	2.22 to 10.43	6.243	2.22 to 10.43	6.288
Ck.%P_2	0.104 to 0.376	0.2320	--	--
Ck.%P^2	0.0108 to 0.1414	0.0563	--	--
Ck.%N x Ck.%P	0.170 to 1.194	0.5838	--	--
N x Ck.%N	0 to 547	127.20	0 to 547	105.04
P x Ck.%N	0 to 367	121.36	0 to 367	100.21
N x Ck.%P	0 to 53.1	12.17	--	--
P x Ck.%P	0 to 40.4	11.33	--	--
Ck.%N x $P_s^{\frac{1}{2}}$	1.33 to 10.01	4.82	--	--
Ck. yield	8.1 to 117.0	72.40	--	--
Y_1 - Δ%P	-0.038 to 0.181	0.0306	--	--
Y_2 - %P	--	--	0.093 to 0.402	0.2590
Y_3 - Δ yield	-21.5 to 107.6	15.65	--	--
Y_4 - yield	--	--	8.1 to 133.4	85.78

[a]Units of the variates are given in Table 19.

ates is beyond the scope of this study. However, the direction and rate of change of the Y variates in the different models on the variables which were included as curvilinear functions will be determined at the mean values of the associated X variates as described above.

In the three regression models of interest, the direction and rate of the change in $\hat{Y}_1$ on the N and P fertilizer levels were positive and decreasing. The average change in $\hat{Y}_1$ on soil test P level was negative in both models in which this variable was present; the slope was decreasing with level, as expected, in the Soil Test P Model but was increasing slowly in the Curvilinear Model. This effect in the Curvilinear Model is due to the correlation between the soil test P and the leaf P variates which was discussed previously. The average change in $\hat{Y}_1$ on the Check percent N level varied among the models; in both the Curvilinear and Leaf P Models, the slope was positive and increasing at the mean levels of the associated X variates but the slope was negative at Check percent N values less than 2.32 and 2.29% in the Curvilinear and Leaf P Models, respectively. In the Soil Test P Model, the slope was negative and becoming more negative with level of Check percent N. In all models, the change in $\hat{Y}_1$ on Check percent N level was somewhat different than the preliminary investigations indicated. In the Curvilinear and Leaf P Models, the behavior may be explained by the high correlation

between the Check percent N and Check percent P variates (Table 26). The partial derivative of change in $\hat{Y}_1$ with respect to Check percent N level thus has little meaning because all of the Check percent P variates, except the interaction with Check percent N, were held constant which is an unrealistic situation.

Although the significance of some of the interaction terms varied among the models, the signs of each of their regression coefficients were consistent among the models. The NP fertilizer interaction was positive as was shown repeatedly in the preliminary investigations. The N x soil test P interaction was positive in both the Curvilinear and Soil Test P Models but had no significance in the latter one; this positive effect was indicated in the preliminary investigations although the interaction was not appreciable (Figure 16). The marked P x soil test P interaction was negative in both models as expected (Figure 10). The Check percent N x Check percent P interaction was negative, as would be expected, since larger increases in $\hat{Y}_1$ would occur when both are at low levels than at high levels. The N x Check percent N interaction was negative in all models as indicated previously (Figure 15). Although not shown clearly in the preliminary investigations (Figure 11), the P x Check percent N interaction was positive in all models. The N x Check percent P and P x Check percent P interactions were negative in all models

as shown previously (Figures 8 and 14). The Check percent N x soil test P interaction was also negative in all models as would be expected. Along with many of these two-factor interactions shown in the previous figures, three-factor interactions of N x P with soil test P, Check percent N and Check percent P also appeared to be present. The effect of these three-factor interactions on $\hat{Y}_1$ needs further study.

The $P_{sub.}$ variate had little effect on $\hat{Y}_1$ except in the Soil Test P Model. Since this variate was highly correlated with the Check percent N, the Check percent P and their interactions, its effect was accounted for by these variates in the Curvilinear and Leaf P Models. The $P_{meth.}$ variate also had little effect except in the Soil Test P Model although its effect was small. This effect was unexpected since plowed-under application of P fertilizer increased the percent P more than disked-in application in the experiments which had methods comparisons (Table 10).

In the use and interpretation of these multiple curvilinear regression equations, the relevant ranges of the X and Y variates from which the equations were derived must be considered. These ranges are given in Table 27. Extrapolating beyond the relevant ranges of the variables may result in a marked increase in the standard error of the $\hat{Y}$ and a marked decrease in the accuracy of the $\hat{Y}$.

The R^2 of the regression equations for the change in percent P ($\hat{Y}_1$) (Table 24) were smaller by 1.2 to 8.5% than the comparable equations for the change in yield ($\hat{Y}_3$) (Table 32). Most agronomists believe that plant composition and, particularly, total nutrient uptake (product of nutrient percentage and dry matter yield) give a better indication of the nutrient status of the plant than yield or yield increases. They believe that adverse factors may affect the yield more than the nutrient uptake. These opinions might be expected to apply in this study. The change in percent P at silking time was estimated, in part, from the leaf composition at the same stage of growth. However, the change in yield was estimated, in part, from the leaf composition at silking but the change in yield was determined after maturity, about 50 days later.

The comparison of the linear correlation coefficients of the change in percent P (Y_1) and the change in yield (Y_3) with the X variates (Table 26) does not explain the difference in the R^2 of the $\hat{Y}_1$ and $\hat{Y}_3$ regression equations since the differences in the correlation coefficients with Y_1 and Y_3 usually were in the direction that would be expected. The R^2 of the Soil Test P, Curvilinear and Leaf P Models for $\hat{Y}_3$ were 1.2, 6.8 and 8.5% higher, respectively, than the R^2 of the corresponding models for $\hat{Y}_1$. This indicates that the differences in the R^2 are associated primarily with the leaf P

variates. It may be that $\hat{Y}_1$ is more affected than $\hat{Y}_3$ by other variables which were not included, such as the variety and weather immediately preceding the sampling. The effect of the three-factor interactions also may be more important in the precision of estimating Y_1 than Y_3. Comparisons of the change in percent P in the corn leaf estimated from the regression equation with the observed value for each observation also may help to explain the lower precision in estimating the change in percent P than change in yield.

This study shows clearly that predicting the change in the percent P in the corn leaf due to N and P fertilization is complicated by a complex interrelationship of many factors. It also points out the futility of trying to explain the changes in plant composition for the entire population from experiments in which one factor is varied and all others are held constant.

3. Percent P

Regressions of the percent P in the corn leaf at any level of N and P fertilization (Y_2) on selected X variates were determined for three multiple regression models (Table 28). The curvilinear multiple regression model (Curvilinear Model) included 17 X variates. In the second model (Curvilinear Reduced Model), the two variates of the percent N variable were deleted to determine how this variable affected

Table 28. Multiple regression statistics for the multiple regression models of the percent P in the corn leaf (Y_2) on selected X variates

Model	Variate	Equation[a] $\hat{Y}_2 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Curvilinear		-139.5[c]			
	N	$-0.2321\ X_1$	0.3002	0.77	0.44
	N^2	$+0.000856\ X_2$	0.000593	1.44	0.16
	P	$+1.331\ X_3$	0.2585	5.15	**
	P^2	$-0.002065\ X_4$	0.000964	2.14	*
	NP	$+0.000682\ X_5$	0.000684	1.00	0.32
	$P_s^{\frac{1}{2}}$	$+58.94\ X_6$	11.77	5.01	**
	P_s	$-6.920\ X_7$	2.582	2.68	**
	$P_{sub.}$	$+1.125\ X_8$	0.1790	6.28	**
	S	$+0.7493\ X_9$	0.6422	1.17	0.25
	$N \times P_s^{\frac{1}{2}}$	$+0.06373\ X_{10}$	0.05314	1.20	0.23
	$P \times P_s^{\frac{1}{2}}$	$-0.3044\ X_{11}$	0.05640	5.40	**
	%N	$+211.2\ X_{12}$	51.51	4.10	**
	$\%N^2$	$-34.19\ X_{13}$	10.63	3.22	**
	Ck.%N	$-58.08\ X_{14}$	50.53	1.15	0.26
	Ck.$\%N^2$	$+17.58\ X_{15}$	10.37	1.70	0.09
	N x Ck.%N	$-0.01944\ X_{16}$	0.1001	0.19	>0.50
	P x Ck.%N	$-0.04260\ X_{17}$	0.08606	0.50	>0.50

[a]Values of a, b_i and $s(b_i)$: x 10^3.

[b]Significance probability level.

[c]This is a, the constant in the regression equation.

Table 28. (Continued)

Model	Variate	Equation[a] $\hat{Y}_2 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Curvilinear Reduced		-69.02[c]			
	N	+0.9648 X_1	0.2129	4.53	**
	N^2	-0.000579 X_2	0.000545	1.06	0.29
	P	+1.005 X_3	0.2571	3.91	**
	P^2	-0.002593 X_4	0.000983	2.64	**
	NP	+0.001632 X_5	0.000679	2.40	*
	$P_s^{\frac{1}{2}}$	+68.96 X_6	11.90	5.80	**
	P_s	-8.994 X_7	2.614	3.44	**
	$P_{sub.}$	+1.118 X_8	0.1832	6.10	**
	S	+0.5229 X_9	0.6552	0.80	0.43
	N x $P_s^{\frac{1}{2}}$	+0.07331 X_{10}	0.05215	1.41	0.17
	P x $P_s^{\frac{1}{2}}$	-0.2941 X_{11}	0.05716	5.14	**
	Ck.%N	+90.44 X_{14}	36.10	2.50	*
	Ck.%N^2	-4.451 X_{15}	7.221	0.62	>0.50
	N x Ck.%N	-0.4008 X_{16}	0.07388	5.42	**
	P x Ck.%N	+0.07092 X_{17}	0.08558	0.83	0.41
Linear		-13.80[c]			
	N	+0.2393 X_1	0.2202	1.09	0.28
	P	+0.7949 X_3	0.2269	3.50	**
	NP	+0.000690 X_5	0.000608	1.13	0.26
	$P_s^{\frac{1}{2}}$	+28.68 X_6	3.621	7.92	**
	$P_{sub.}$	+1.165 X_8	0.1814	6.42	**

Table 28. (Continued)

Model	Variate	Equation[a] $\hat{Y}_2 = a + \sum b_i X_i$	$s(b_i)$[a]	t	Sign. level[b]
Linear					
	S	$+0.7261\ X_9$	0.6445	1.13	0.26
	$N \times P_s^{\frac{1}{2}}$	$+0.03605\ X_{10}$	0.05216	0.69	0.49
	$P \times P_s^{\frac{1}{2}}$	$-0.2448\ X_{11}$	0.05614	4.36	**
	%N	$+50.66\ X_{12}$	9.833	5.15	**
	Ck.%N	$+21.81\ X_{14}$	10.46	2.01	*
	N x Ck.%N	$-0.1557\ X_{16}$	0.08371	1.86	0.07
	P x Ck.%N	$+0.04603\ X_{17}$	0.08471	0.54	>0.50

the regression coefficients of the other variates with which it was highly correlated. In the third model (Linear Model), five of the curvilinear variates (squared terms) were deleted from the Curvilinear Model in order to determine the value of the five curvilinear functions in estimating Y_2. The $P_{meth.}$ variate was deleted from the Curvilinear and Linear Models because of its confounding with other factors. Although the method of P application had a considerable effect on yield ($\hat{Y}_4$), it had little effect on the $\hat{Y}_2$ since the R^2 of both models were reduced by only 0.4% due to deletion of this variate.

The regression of $\hat{Y}_2$ on the X variates was highly significant in all three models (Table 29). The addition of the

Table 29. Analyses of variance for the multiple regression models of the percent P in the corn leaf (Y_2) on selected X variates

Model	Source of variation	d.f.	S.S.	M.S.	F	R	R^2
Curvilinear	Regression	17	.79040	.04649	44**	.7564	.5722
	Error	556	.59092	.00106			
Curvilinear Reduced	Regression	15	.75759	.05051	45**	.7406	.5484
	Error	558	.62373	.00112			
Linear	Regression	12	.76209	.06351	58**	.7428	.5517
	Error	561	.61923	.00110			
Curvilinear vs. Curvilinear Reduced	Regression on 15 variates	15	.75759				
	Added reduction by percent N variates	2	.03281	.01640	15**		
	Error	556	.59092	.00106			
Curvilinear vs. Linear	Regression on 12 variates	12	.76209				
	Added reduction by 5 curvilinear variates	5	.02831	.00566	5.3**		
	Error	556	.59092	.00106			

two variates for the percent N variable to the Curvilinear Model had a highly significant effect on the R^2 although the increase in the R^2 was only 2.4%. The addition of the curvilinear variates also had a highly significant effect but the R^2 of the Curvilinear Model was only 2% higher than that of the Linear Model. Since the highest linear correlation of Y_2 was with the %N variate whose r^2 was 0.308 (Table 30), there

Table 30. Linear correlation coefficients (r) between the X variates associated with the percent P in the corn leaf (Y_2) and between the X variates and Y_2

X variate	X variate								
	N^2	P	P^2	NP	$P_s^{\frac{1}{2}}$	P_s	$P_{sub.}$	S	N x $P_s^{\frac{1}{2}}$
N	.92[a]	.23	.32	.70	.04	.03	-.06	-.01	.93
N^2	1.00	.28	.38	.73	.01	.01	-.09	.00	.84
P		1.00	.93	.65	-.04	-.04	-.16	.01	.21
P^2			1.00	.74	-.05	-.04	-.16	.03	.29
NP				1.00	.02	.01	-.11	.01	.65
$P_s^{\frac{1}{2}}$					1.00	.98	.10	-.02	.29
P_s						1.00	.09	-.03	.27
$P_{sub.}$							1.00	.05	-.03
S								1.00	-.03
N x $P_s^{\frac{1}{2}}$									1.00

	X variate							
	P x $P_s^{\frac{1}{2}}$	%N	$\%N^2$	Ck. %N	Ck. $\%N^2$	N x Ck.%N	P x Ck.%N	%P (Y_2)
N	.24	.27	.25	-.11	-.11	.97	.20	.14
N^2	.27	.20	.20	-.09	-.09	.89	.25	.14
P	.90	-.03	-.03	-.05	-.05	.22	.97	.32
P^2	.82	-.03	-.02	-.07	-.07	.30	.88	.27
NP	.62	.15	.15	-.08	-.08	.68	.61	.28
$P_s^{\frac{1}{2}}$	.27	.10	.10	.02	.02	.06	-.03	.29
P_s	.26	.06	.06	-.01	-.02	.05	-.03	.25
$P_{sub.}$	-.11	.14	.14	.18	.18	-.02	-.13	.24
S	-.03	-.12	-.11	-.11	-.09	-.03	-.02	-.01
N x $P_s^{\frac{1}{2}}$	.31	.30	.30	-.06	-.07	.92	.20	.22
P x $P_s^{\frac{1}{2}}$	1.00	.02	.02	-.02	-.02	.24	.89	.35
%N		1.00	.994	.83	.83	.36	.11	.56
$\%N^2$			1.00	.84	.85	.36	.12	.55
Ck.%N				1.00	.995	.05	.13	.49
Ck.$\%N^2$					1.00	.05	.13	.49
N x Ck.%N						1.00	.23	.20
P x Ck.%N							1.00	.39

[a]Number of observations = 574. Values of r larger than 0.084 and 0.110 are significant at the 5% and 1% levels, respectively.

was a large gain in the precision of estimating Y_2 by including other variates in the multiple regression equations.

The partial regression coefficients of the P, P^2, $P_s^{\frac{1}{2}}$, P_s, $P_{sub.}$ and P x $P_s^{\frac{1}{2}}$ variates were significant at the 5% level or less in both the Curvilinear and Curvilinear Reduced Models (Table 28). Since there is little interest in the Linear Model except as a method of testing the value of the curvilinear functions and since its regression statistics were similar in most respects to the Curvilinear Model, it will not be discussed further. The significance levels of the N^2, S, N x $P_s^{\frac{1}{2}}$ and P x Ck.%N regression coefficients were similar in both models. The significance of the regression coefficients of the other variates varied considerably between the two models. Most of those whose t values were less than one could be deleted from the equations with little loss in precision in estimating Y_2. However, the N variate in the Curvilinear Model should be retained.

In both regression models, the change in $\hat{Y}_2$ on P fertilizer and soil test P levels was positive and decreasing at the means of the X variates in the partial derivative. These effects were indicated by the signs of their partial regression coefficients and also were shown in the preliminary investigations (Figures 9 and 18). The slope of $\hat{Y}_2$ on the percent N level in the Curvilinear Model was positive and decreasing. Since no interaction variates with percent N were

included, the signs of the regression coefficients of the %N and $\%N^2$ variates indicated the direction of the slope and change in slope of $\hat{Y}_2$.

In the Curvilinear Model, the slope of $\hat{Y}_2$ on N fertilizer level was negative and becoming less negative at the means of the X variates in the partial derivative. The slope became zero at 74 pounds of N, other X variates constant, and increased at higher levels. The slope of $\hat{Y}_2$ on Check percent N level was positive and increasing. The behavior of both of these variables, which was contrary to what was found in the preliminary investigations (Table 6, Figure 19), appeared to be due to highly significant correlations among several of the X variates (Table 30). The N fertilizer was highly correlated with its interactions, interactions with P fertilizer and the percent N in the leaf at any N and P fertilizer treatment. The Check percent N was highly correlated with its interactions and the percent N at any fertilizer treatment.

The variates of the percent N variable then were deleted from the Curvilinear Model to determine how this variable affected the regression coefficients of the other variates, such as the N fertilizer and Check percent N variates, with which it was highly correlated. Also, the equation of the Curvilinear Reduced Model avoids the duplication of the Check percent N and percent N variates that occurs in the Curvilinear Model when the N and P levels are zero.

The change in $\hat{Y}_2$ on the N fertilizer and Check percent N levels was quite different after deleting the percent N variates. The slopes in both cases were positive and decreasing as was shown in the preliminary investigations. The signs and significance levels of the regression coefficients of the N and Check percent N variates also were reversed in the two models. The low t values of the N^2 and Ck.%N^2 variates in the Curvilinear Reduced Model indicated that the effect of the N and Check percent N variables on $\hat{Y}_2$ was primarily linear in the presence of interaction terms.

The regression statistics of these two models illustrate the effect of a variable on the partial regression coefficients of other variables with which it is highly correlated. The difficulty in interpreting the effect of the variables on the dependent variate from their partial regression coefficients when they are correlated with other variables is also apparent.

The NP interaction was positive, as expected, although its significance was much greater in the Curvilinear Reduced than in the Curvilinear Model. The N x soil test P interaction was positive but significant at only the 17 to 23% level. The positive effect was indicated in the preliminary investigations although the interaction was not appreciable (Figure 16). The P x soil test P interaction was negative as expected (Figure 10). The N x Check percent N interaction was

negative in both models as expected (Figure 15); however, it had no significance in the Curvilinear Model but was highly significant in the Curvilinear Reduced Model. The P x Check percent N interaction had little effect on $\hat{Y}_2$ as expected (Figure 11).

Although the linear correlation coefficient of Y_2 and stand level was zero, the partial regression coefficient in all models was positive but significant at only the 0.25 to 0.43 levels. At a constant N level in the leaf or as nearly constant as is possible in view of the high correlation between the percent N and percent P in the leaf, these multiple regressions indicate that an increased stand level may have little effect on the percent P in the corn leaf.

In summary, the percent P in the corn leaf at any level of N and P fertilization, within the ranges used in this study (Table 27), can be predicted with reasonable precision from the variables included in these regression equations. The maximum R^2 of the regression of the percent P on the selected X variates was 0.572. The percent P in the corn leaf also may be predicted without leaf composition data provided that soil test N data were available to substitute for the Check percent N data which were used to indicate the N availability in the soil.

4. Change in yield

Regressions of the change in corn yield due to N and P fertilization (Y_3) on selected X variates were determined for 10 multiple regression models, eight of which are shown in Table 31. The multiple curvilinear regression model (designated Curvilinear Complete Model) included 23 X variates. A linear multiple regression model (Linear Complete Model) with 18 X variates was included to determine the value of the five curvilinear functions in estimating Y_3.

The soil test P and leaf P variates were compared for estimating Y_3 in several multiple curvilinear regression models. In one comparison the five variates associated with the soil test P level in the plow-layer and 13 common variates (Soil Test P Model) were compared with the five variates associated with the Check percent P level in the leaf and the 13 common variates (Leaf P-I Model). In another model (Leaf P-II Model), the $P_{sub.}$ variate was deleted from the Leaf P-I Model so that the six soil test P variates and 12 common variates could be compared with the five leaf P variates and the 12 common variates. The $P_{sub.}$ variate was considered a common variate in the comparison between the Soil Test P and Leaf P-I Models for the cases where the soil test from only the plow-layer is available and the value of the $P_{sub.}$ variate is estimated. For a more precise comparison of the soil test P and leaf P variates in estimating Y_3 when the value of the

Table 31. Multiple regression statistics for the multiple regression models of the change in corn yield (Y_3) on selected X variates

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Curvilinear Complete		-72.5[b]			
	N	+0.5284 X_1	0.06416	8.24	**
	N^2	-0.000872 X_2	0.000151	5.78	**
	P	+0.4186 X_3	0.07582	5.52	**
	P^2	-0.001465 X_4	0.000268	5.47	**
	NP	+0.001353 X_5	0.000212	6.38	**
	$P_s^{\frac{1}{2}}$	+22.41 X_6	6.641	3.37	**
	P_s	-2.177 X_7	0.8256	2.64	**
	$P_{sub.}$	-0.02999 X_8	0.05812	0.52	>0.50
	$P_{meth.}$	+0.4024 X_9	0.9586	0.42	>0.50
	S	+0.7602 X_{10}	0.2194	3.46	**
	$N \times P_s^{\frac{1}{2}}$	+0.05341 X_{11}	0.01779	3.00	**
	$P \times P_s^{\frac{1}{2}}$	-0.05772 X_{12}	0.02107	2.74	**
	Ck.%N	+40.12 X_{13}	12.87	3.12	**
	Ck.%N^2	+3.156 X_{14}	3.368	0.94	0.35
	Ck.%P	-48.91 X_{15}	78.41	0.62	>0.50
	Ck.%P^2	+1103.6 X_{16}	211.6	5.22	**
	Ck.%N x Ck.%P	-185.9 X_{17}	44.65	4.16	**

[a]Significance probability level.

[b]This is a, the constant in the regression equation.

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Curvilinear Complete					
	N x Ck.%N	$-0.1647\ X_{18}$	0.02435	6.76	**
	P x Ck.%N	$+0.1810\ X_{19}$	0.03169	5.71	**
	N x Ck.%P	$-0.2213\ X_{20}$	0.2496	0.89	0.38
	P x Ck.%P	$-2.295\ X_{21}$	0.3048	7.53	**
	Ck.%N x $P_s^{\frac{1}{2}}$	$-4.857\ X_{22}$	1.926	2.52	*
	Ck. yield	$-0.1076\ X_{23}$	0.03014	3.57	**
Curvilinear Reduced		-47.9[b]			
	N	$+0.5335\ X_1$	0.06498	8.21	**
	N^2	$-0.000864\ X_2$	0.000155	5.57	**
	P	$+0.4315\ X_3$	0.07669	5.63	**
	P^2	$-0.001460\ X_4$	0.000271	5.39	**
	NP	$+0.001332\ X_5$	0.000215	6.20	**
	$P_s^{\frac{1}{2}}$	$+19.14\ X_6$	6.664	2.87	**
	P_s	$-2.240\ X_7$	0.8363	2.68	**
	$P_{sub.}$	$-0.04154\ X_8$	0.05877	0.71	0.48
	$P_{meth.}$	$-0.4888\ X_9$	0.9403	0.52	>0.50
	S	$+0.3907\ X_{10}$	0.1961	1.99	*
	N x $P_s^{\frac{1}{2}}$	$+0.05436\ X_{11}$	0.01798	3.02	**
	P x $P_s^{\frac{1}{2}}$	$-0.05519\ X_{12}$	0.02133	2.59	**
	Ck.%N	$+27.90\ X_{13}$	12.53	2.23	*

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Curvi-linear Reduced					
	Ck.%N^2	$+6.420\ X_{14}$	3.282	1.96	*
	Ck.%P	$-99.14\ X_{15}$	78.11	1.27	0.21
	Ck.%P^2	$+1349.4\ X_{16}$	202.5	6.66	**
	Ck.%N x Ck.%P	$-218.8\ X_{17}$	48.16	4.54	**
	N x Ck.%N	$-0.1706\ X_{18}$	0.02464	6.92	**
	P x Ck.%N	$+0.1738\ X_{19}$	0.03204	5.42	**
	N x Ck.%P	$-0.1837\ X_{20}$	0.2525	0.73	0.47
	P x Ck.%P	$-2.288\ X_{21}$	0.3092	7.40	**
	Ck.%N x $P_s^{\frac{1}{2}}$	$-3.641\ X_{22}$	1.917	1.90	0.06
Linear Complete		-42.8[b]			
	N	$+0.3357\ X_1$	0.06246	5.38	**
	P	$+0.2157\ X_3$	0.07241	2.98	**
	NP	$+0.001197\ X_5$	0.000229	5.23	**
	$P_s^{\frac{1}{2}}$	$+10.25\ X_6$	5.252	1.95	*
	$P_{sub.}$	$+0.01930\ X_8$	0.06276	0.31	>0.50
	$P_{meth.}$	$+0.6438\ X_9$	1.048	0.61	>0.50
	S	$+0.8113\ X_{10}$	0.2298	3.53	**
	N x $P_s^{\frac{1}{2}}$	$+0.05592\ X_{11}$	0.01926	2.90	**
	P x $P_s^{\frac{1}{2}}$	$-0.05417\ X_{12}$	0.02280	2.38	*
	Ck.%N	$+17.92\ X_{13}$	6.353	2.82	**
	Ck.%P	$+91.79\ X_{15}$	65.51	1.40	0.17

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Linear Complete					
	Ck.%N x Ck.%P	$-33.30\ X_{17}$	22.20	1.50	0.14
	N x Ck.%N	$-0.1442\ X_{18}$	0.02585	5.58	**
	P x Ck.%N	$+0.1788\ X_{19}$	0.03446	5.19	**
	N x Ck.%P	$-0.2277\ X_{20}$	0.2698	0.84	0.40
	P x Ck.%P	$-2.152\ X_{21}$	0.3323	6.48	**
	Ck.%N x $P_s^{\frac{1}{2}}$	$-3.812\ X_{22}$	2.010	1.90	0.06
	Ck. yield	$-0.1405\ X_{23}$	0.03076	4.57	**
Linear Reduced		-13.1[b]			
	N	$+0.3555\ X_1$	0.06366	5.58	**
	P	$+0.2368\ X_3$	0.07381	3.21	**
	NP	$+0.001167\ X_5$	0.000234	4.99	**
	$P_s^{\frac{1}{2}}$	$+5.526\ X_6$	5.260	1.05	0.29
	$P_{sub.}$	$+0.000068\ X_8$	0.06397	0.00	>0.50
	$P_{meth.}$	$-0.6525\ X_9$	1.030	0.63	>0.50
	S	$+0.3636\ X_{10}$	0.2123	1.71	0.09
	N x $P_s^{\frac{1}{2}}$	$+0.05659\ X_{11}$	0.01967	2.88	**
	P x $P_s^{\frac{1}{2}}$	$-0.05103\ X_{12}$	0.02328	2.19	*
	Ck.%N	$+7.534\ X_{13}$	6.060	1.24	0.22
	Ck.%P	$+9.167\ X_{15}$	64.32	0.14	>0.50
	Ck.%N x Ck.%P	$-8.797\ X_{17}$	22.01	0.40	>0.50
	N x Ck.%N	$-0.1589\ X_{18}$	0.02619	6.07	**

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Linear Reduced					
	P x Ck.%N	$+0.1688\ X_{19}$	0.03513	4.80	**
	N x Ck.%P	$-0.1467\ X_{20}$	0.2749	0.53	>0.50
	P x Ck.%P	$-2.1457\ X_{21}$	0.3298	6.51	**
	Ck.%N x $P_s^{\frac{1}{2}}$	$-2.230\ X_{22}$	2.021	1.10	0.27
Soil Test P		-66.9[b]			
	N	$+0.4276\ X_1$	0.07169	5.96	**
	N^2	$-0.000907\ X_2$	0.000172	5.27	**
	P	$+0.4010\ X_3$	0.08621	4.65	**
	P^2	$-0.001279\ X_4$	0.000304	4.21	**
	NP	$+0.001495\ X_5$	0.000238	6.28	**
	$P_s^{\frac{1}{2}}$	$+11.99\ X_6$	6.870	1.74	0.09
	P_s	$+0.2821\ X_7$	0.8840	0.32	>0.50
	$P_{sub.}$	$-0.1088\ X_8$	0.06321	1.72	0.09
	$P_{meth.}$	$+0.4445\ X_9$	1.092	0.41	>0.50
	S	$+1.239\ X_{10}$	0.2453	5.05	**
	N x $P_s^{\frac{1}{2}}$	$+0.04593\ X_{11}$	0.01716	2.68	**
	P x $P_s^{\frac{1}{2}}$	$-0.1606\ X_{12}$	0.01927	8.33	**
	Ck.%N	$+40.09\ X_{13}$	13.62	2.94	**
	Ck.%N^2	$-5.536\ X_{14}$	2.483	2.23	*
	N x Ck.%N	$-0.1410\ X_{18}$	0.02379	5.93	**
	P x Ck.%N	$+0.04258\ X_{19}$	0.02828	1.51	0.14

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Soil Test P					
	Ck.%N x $P_s^{\frac{1}{2}}$	$-4.079\ X_{22}$	2.059	1.98	*
	Ck. yield	$-0.2128\ X_{23}$	0.03154	6.75	**
Soil Test P Reduced		-10.2^b			
	N	$+0.4286\ X_1$	0.07511	5.71	**
	N^2	$-0.000898\ X_2$	0.000180	4.99	**
	P	$+0.4268\ X_3$	0.09023	4.73	**
	P^2	$-0.001218\ X_4$	0.000319	3.82	**
	NP	$+0.001477\ X_5$	0.000249	5.93	**
	$P_s^{\frac{1}{2}}$	$-2.354\ X_6$	6.845	0.34	>0.50
	P_s	$+1.065\ X_7$	0.9182	1.16	0.25
	$P_{sub.}$	$-0.1556\ X_8$	0.06583	2.36	*
	$P_{meth.}$	$-1.616\ X_9$	1.098	1.47	0.15
	S	$+0.5047\ X_{10}$	0.2304	2.19	*
	N x $P_s^{\frac{1}{2}}$	$+0.05142\ X_{11}$	0.01795	2.86	**
	P x $P_s^{\frac{1}{2}}$	$-0.1566\ X_{12}$	0.01988	7.88	**
	Ck.%N	$+7.178\ X_{13}$	13.31	0.54	>0.50
	Ck.$\%N^2$	$-1.245\ X_{14}$	2.514	0.50	>0.50
	N x Ck.%N	$-0.1456\ X_{18}$	0.02491	5.84	**
	P x Ck.%N	$+0.02783\ X_{19}$	0.02954	0.94	0.35
	Ck.%N x $P_s^{\frac{1}{2}}$	$-0.5444\ X_{22}$	2.087	0.26	>0.50

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Leaf P I		-40.2[b]			
	N	+0.5273 X_1	0.06437	8.19	**
	N^2	-0.000928 X_2	0.000154	6.03	**
	P	+0.3354 X_3	0.07463	4.49	**
	P^2	-0.001403 X_4	0.000274	5.12	**
	NP	+0.001489 X_5	0.000216	6.89	**
	$P_{sub.}$	-0.04713 X_8	0.05952	0.79	0.43
	$P_{meth.}$	+0.4879 X_9	0.9399	0.52	>0.50
	S	+0.6624 X_{10}	0.2181	3.04	**
	Ck.%N	+23.51 X_{13}	11.62	2.02	*
	Ck.%N^2	+4.654 X_{14}	3.370	1.38	0.17
	Ck.%P	+58.05 X_{15}	72.73	0.80	0.43
	Ck.%P^2	+961.1 X_{16}	210.3	4.57	**
	Ck.%N x Ck.%P	-195.5 X_{17}	44.83	4.36	**
	N x Ck.%N	-0.1720 X_{18}	0.02455	7.01	**
	P x Ck.%N	+0.2108 X_{19}	0.03127	6.74	**
	N x Ck.%P	+0.2771 X_{20}	0.2152	1.29	0.20
	P x Ck.%P	-2.796 X_{21}	0.2493	11.22	**
	Ck. yield	-0.08979 X_{23}	0.03009	2.98	**
Leaf P I Reduced		-24.2[b]			
	N	+0.5370 X_1	0.06484	8.28	**
	N^2	-0.000912 X_2	0.000155	5.88	**

Table 31. (Continued)

Model	Variate	Equation $\hat{Y}_3 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Leaf P I Reduced					
	P	$+0.3489\ X_3$	0.07513	4.64	**
	P^2	$-0.001398\ X_4$	0.000276	5.06	**
	NP	$+0.001463\ X_5$	0.000217	6.74	**
	$P_{sub.}$	$-0.05660\ X_8$	0.05995	0.94	0.35
	$P_{meth.}$	$-0.2919\ X_9$	0.9104	0.32	>0.50
	S	$+0.3758\ X_{10}$	0.1976	1.90	0.06
	Ck.%N	$+16.27\ X_{13}$	11.46	1.42	0.16
	Ck.%N^2	$+7.079\ X_{14}$	3.299	2.15	*
	Ck.%P	$-5.296\ X_{15}$	70.17	0.08	>0.50
	Ck.%P^2	$+1181.9\ X_{16}$	198.6	5.95	**
	Ck.%N x Ck.%P	$-219.1\ X_{17}$	44.51	4.92	**
	N x Ck.%N	$-0.1789\ X_{18}$	0.02465	7.26	**
	P x Ck.%N	$+0.2036\ X_{19}$	0.03145	6.47	**
	N x Ck.%P	$+0.3127\ X_{20}$	0.2167	1.44	0.16
	P x Ck.%P	$-2.769\ X_{21}$	0.2514	11.01	**

$P_{sub.}$ variate is available, the Soil Test P and Leaf P-II Models are more appropriate.

Since the Check percent N in the leaf was assumed to be an estimate of the N availability in the soil, its variates

were included as common variates in the comparisons between the soil test P and leaf P variates in estimating Y_3.

The variate for the Check yield was included in the five previously-discussed regression models. Since the Check yield may not be known in many cases, alternative regressions without this variate were calculated. The Check yield variate was deleted from each of the models according to the method given by Snedecor (74). The models without the Check yield variate were designated Reduced Models.

The regression statistics of all the models except the Leaf P-II and Leaf P-II Reduced Models are given in Table 31. The deletion of the $P_{sub.}$ variate from the Leaf P-I and Leaf P-I Reduced Models had very little effect on the R^2 or the regression statistics of the corresponding Leaf P-II or Leaf P-II Reduced Models.

The sum of squares due to regression was highly significant in all regression models (Table 32) with the R^2 of the individual equations varying from 0.568 to 0.705. Since the highest linear correlation of Y_3 was with the NP variate whose r^2 was 0.336 (Table 26), there was a large gain in the precision of estimating Y_3 due to the additional variates.

The added reduction in the residual error due to the five curvilinear variates (squared terms) was highly significant (Table 33) with the R^2 of the Curvilinear Complete and Curvilinear Reduced Models being 6.0 and 6.8% higher than their

Table 32. Analyses of variance for the multiple regression models of the change in yield (Y_3) on selected X variates

Model	Source of variation	d.f.	S.S.	M.S.	F	R	R^2
Curvilinear Complete	Regression	23	80196	3486.8	47**	.8396	.7050
	Error	450	33559	74.6			
Curvilinear Reduced	Regression	22	79245	3602.0	47**	.8347	.6966
	Error	451	34510	76.5			
Linear Complete	Regression	18	73317	4073.2	46**	.8028	.6445
	Error	455	40437	88.9			
Linear Reduced	Regression	17	71464	4203.8	45**	.7926	.6282
	Error	456	42291	92.7			
Soil Test P	Regression	18	69118	3839.9	39**	.7795	.6076
	Error	455	44637	98.1			
Soil Test P Reduced	Regression	17	64649	3802.9	35**	.7539	.5683
	Error	456	49105	107.7			
Leaf P-I	Regression	18	77913	4328.5	55**	.8276	.6849
	Error	455	35841	78.8			
Leaf P-I Reduced	Regression	17	77212	4541.9	57**	.8239	.6788
	Error	456	36543	80.1			
Leaf P-II	Regression	17	77864	4580.2	58**	.8273	.6845
	Error	456	35891	78.7			
Leaf P-II Reduced	Regression	16	77140	4821.3	60**	.8235	.6781
	Error	457	36614	80.1			

corresponding linear models. The added reduction due to the five leaf P variates was also highly significant with the R^2 of the Curvilinear Complete and Curvilinear Reduced Models being 9.7 and 12.8% higher than the Soil Test P and Soil Test P Reduced Models, respectively. The added leaf P variates thus gave a large gain in the precision of estimating Y_3 and

Table 33. Analyses of variance of the reduction in the residual error due to the curvilinear, leaf P and soil test P variates in the multiple regressions of the change in yield (Y_3) on selected X variates

Models	Source of variation	d.f.	S.S.	M.S.	F
Curvilinear Complete vs. Linear Complete	Regression on 18 variates	18	73317		
	Added reduction by 5 curvilinear variates	5	6879	1375.8	18**
	Error	450	33559	74.6	
Curvilinear Reduced vs. Linear Reduced	Regression on 17 variates	17	71464		
	Added reduction by 5 curvilinear variates	5	7781	1556.2	20**
	Error	451	34510	76.5	
Curvilinear Complete vs. Soil Test P	Regression on 18 variates	18	69118		
	Added reduction by 5 leaf P variates	5	11078	2215.6	30**
	Error	450	33559	74.6	
Curvilinear Reduced vs. Soil Test P Reduced	Regression on 17 variates	17	64649		
	Added reduction by 5 leaf P variates	5	14596	2919.2	38**
	Error	451	34510	76.5	
Curvilinear Complete vs. Leaf P-I	Regression on 18 variates	18	77913		
	Added reduction by 5 soil test P variates	5	2283	456.6	6.1**
	Error	450	33559	74.6	
Curvilinear Reduced vs. Leaf P-I Reduced	Regression on 17 variates	17	77212		
	Added reduction by 5 soil test P variates	5	2033	406.6	5.3**
	Error	451	34510	76.5	

were more effective in the models without the Check yield variate.

Although the added reduction due to the five soil test P variates was highly significant (Table 33), the R^2 of the Curvilinear Complete and Curvilinear Reduced Models were only 2.0 and 1.8% higher than the Leaf P-I and Leaf P-I Reduced Models. There was little difference between the Leaf P-I and Leaf P-II Models due to the deletion of the $P_{sub.}$ variate as shown by the R^2 (Table 32) or by the significance level of the partial regression coefficient of the $P_{sub.}$ variate in the Leaf P-I Models (Table 31).

The added reduction in the residual error due to the Check yield variate was highly significant in all models as shown by its highly significant partial regression coefficient. The R^2 of the Curvilinear Complete, Linear Complete, Soil Test P, Leaf P-I and Leaf P-II Models were 0.8, 1.6, 3.9, 0.6 and 0.6% higher than in their respective Reduced Models. The gain in precision due to the addition of the Check yield variate thus was most marked in the Soil Test P Model.

Considerably higher precision in estimating Y_3 was obtained from the leaf P variates than from the soil test P variates, particularly in the absence of the Check yield variate. The R^2 of the Leaf P-II and Leaf P-II Reduced Models were 7.7 and 11.0% higher than the Soil Test P and Soil Test P Reduced Models, respectively. These differences were some-

what less than in the comparison between the r^2 of the yield response to P fertilizer on soil test P level and the r^2 of the yield response on the percent P in the leaf as shown in the preliminary investigations (Table 15). The r^2 of the yield response to N fertilizer and leaf N level also appeared to be appreciably higher than that of the yield response and soil test N level in the preliminary investigations (Table 17). Although no comparison of these two methods of estimating the N availability in the soil was included in these multiple regression analyses, it appears that the R^2 of $\hat{Y}_3$ on both the leaf N and P levels may be up to 15 to 20% higher than that of $\hat{Y}_3$ on the soil test N and P levels.

The significance level of more than half of the partial regression coefficients was similar in all models but that of the others varied considerably among the different models. The significance levels are given in Table 31 and summarized in Table 34. Since there is little interest in the Linear Complete and Linear Reduced Models, they will not be discussed further. The partial regression coefficients of the N, N^2, P, P^2, NP, S, N x $P_s^{\frac{1}{2}}$, P x $P_s^{\frac{1}{2}}$, Ck.%P^2, Ck.%N x Ck.%P, N x Ck.%N, P x Ck.%P and Ck. yield variates were significant at the 5% level or less in the models in which they occurred. However, the significance level of the regression coefficients of the other variates varied widely among the models. Many of the variates whose significance level was greater than 0.32

Table 34. Summary of the significance probability levels of the t values in the multiple regressions of Y_3 on selected X variates

Variate	Significance probability level of the t values in the following multiple regression models[a]							
	1	2	3	4	5	6	7	8
N	**	**	**	**	**	**	**	**
N^2	**	**	--	--	**	**	**	**
P	**	**	**	**	**	**	**	**
P^2	**	**	--	--	**	**	**	**
NP	**	**	**	**	**	**	**	**
$P_s^{\frac{1}{2}}$	**	**	*	0.29	0.09	>0.50	--	--
P_s	**	**	--	--	>0.50	0.25	--	--
$P_{sub.}$	>0.50	0.48	>0.50	>0.50	0.09	*	0.43	0.35
$P_{meth.}$	>0.50	>0.50	>0.50	>0.50	>0.50	0.15	>0.50	>0.50
S	**	*	**	0.09	**	*	**	0.06
$N \times P_s^{\frac{1}{2}}$	**	**	**	**	**	**	--	--
$P \times P_s^{\frac{1}{2}}$	**	**	*	*	**	**	--	--
Ck.%N	**	*	**	0.22	**	>0.50	*	0.16
Ck.%N^2	0.35	*	--	--	*	>0.50	0.17	*
Ck.%P	>0.50	0.21	0.17	>0.50	--	--	0.43	>0.50
Ck.%P^2	**	**	--	--	--	--	**	**
Ck.%N x Ck.%P	**	**	0.14	>0.50	--	--	**	**
N x Ck.%N	**	**	**	**	**	**	**	**
P x Ck.%N	**	**	**	**	0.14	0.35	**	**
N x Ck.%P	0.38	0.47	0.40	>0.50	--	--	0.20	0.16
P x Ck.%P	**	**	**	**	--	--	**	**
Ck.%N x $P_s^{\frac{1}{2}}$	*	0.06	0.06	0.27	*	>0.50	--	--
Ck. yield	**	--	**	--	**	--	**	--

[a]The multiple regression models are in the same numerical order as listed in Table 31.

could be deleted from the regression equations with little loss in precision in estimating Y_3. However, the linear variates such as the $P_s^{\frac{1}{2}}$, Ck.%N and Ck.%P variates in the curvilinear functions should be retained in the regression equations although their significance level was greater than 0.32.

The significance level of all the regression coefficients was similar in the Curvilinear Complete and Leaf P-I Models and in the Curvilinear Reduced and Leaf P-I Reduced Models. Addition of the soil test P variates thus had little effect on the significance level of the other regression coefficients in these models. However, the significance level of the regression coefficients of the $P_s^{\frac{1}{2}}$, P_s, $P_{sub.}$, Ck.%N, Ck.%N^2, P x Ck.%N and Ck.%N x $P_s^{\frac{1}{2}}$ variates varied widely between the Curvilinear and Soil Test P Models. The changes in the significance levels due to the addition of the leaf P variates were not always in the same direction nor were they the same in the models with the Check yield variate as in the Reduced Models. The significance of the Check percent N variates and interactions generally was higher in the Curvilinear Models than in the Soil Test P Models. This effect probably was due to the high correlation between the Check percent N and Check percent P variates (Table 26).

The $P_{sub.}$ variate had no significance in the Curvilinear Models but was significant at the 5 to 9% levels in the Soil Test P Models. However, the deletion of the $P_{sub.}$ variate

only decreased the R^2 of the Soil Test P and Soil Test P Reduced Models 0.3 and 0.5%, respectively.

Deletion of the Check yield variate changed the significance of some of the regression coefficients, particularly in the Soil Test P Models. In the Soil Test P Reduced Model, the significance of the $P_s^{\frac{1}{2}}$, Ck.%N, Ck.%N^2 and Ck.%N x $P_s^{\frac{1}{2}}$ variates was reduced from that of these variates in the Soil Test P Model. In the Curvilinear and Leaf P-I Models, deletion of the Check yield decreased the significance of the S and Ck.%N variates and increased the significance of the Ck.%N^2 variate. Considerable change in the regression coefficients due to deletion of the Check yield would be expected because of high correlation between it and many of the other variates and, particularly, because many of the correlations between the other X variates and the Check yield were of opposite sign to those between the X variates and Y_3 (Table 26).

The change in $\hat{Y}_3$ due to increasing level of the X variables is of interest in these regressions. In the preliminary investigations, the change in the yield response due to N or P fertilizer had a positive and decreasing slope with increasing levels (Figures 22, 24 and 30). Therefore, in these single-variable functions, the change in $\hat{Y}_3$ should have the form, $\hat{Y} = a + b_1X - b_2X^2$. The change in $\hat{Y}_3$ due to P fertilizer on the soil test P level (Figure 23) and the change in $\hat{Y}_3$ due to both N and P fertilizer on the Check percent P level

(Figures 21 and 26) had negative slopes with decreasing rates of change. These functions should have the form, $\hat{Y} = a - b_1X + b_2X^2$. The change in $\hat{Y}_3$ due to N fertilizer on Check percent N level had a negative slope but little deviation from linearity (Figure 29). The change in $\hat{Y}_3$ due to N fertilizer on the soil test P level (Figure 27) and the change in $\hat{Y}_3$ due to P fertilizer on the Check percent N level (Figure 28) had slopes of opposite sign in the absence and presence of the other nutrient; in these cases, the change in $\hat{Y}_3$ was primarily a function of the interaction rather than of the single variable.

As discussed in the section on the change in percent P ($\hat{Y}_1$), it is difficult to determine the direction and rate of change of the dependent variate in the multiple regression equations from the signs of the partial regression coefficients or by varying one variable and holding all others constant. The change in $\hat{Y}_3$ on the level of an X variable was investigated only at the means of the other variates in the partial derivatives; the method has been described previously. The partial regression coefficients of the variates in the different models are summarized in Table 35.

The change in $\hat{Y}_3$ on N and P fertilizer levels was positive and decreasing over most of the relevant range in all of the regression models. The signs of the linear and squared variates in both the N and P quadratic functions were as expected. The slope of $\hat{Y}_3$ on the soil test P level was positive

Table 35. Summary of the partial regression coefficients (b_i) in the multiple regressions of Y_3 on selected X variates

Variate	b_i for the designated variate in the following multiple regressions[a]							
	1	2	3	4	5	6	7	8
N_2	.53[b]	.53	.34	.36	.43	.43	.53	.54
N^2	-.00087	-.00086	--	--	-.00091	-.00090	-.00093	-.00091
P_2	.42	.43	.22	.24	.40	.43	.34	.35
P^2	-.0015	-.0015	--	--	-.0013	-.0012	-.0014	-.0014
$NP_{\frac{1}{2}}$	.0014	.0013	.0012	.0012	.0015	.0015	.0015	.0015
$P_s^{\frac{1}{2}}$	22	19	10	5.5	12	-2.4	--	--
P_s	-2.2	-2.2	--	--	.28	1.1	--	--
$P_{sub.}$	-.030	-.042	.019	.0001	-.11	-.16	-.047	-.057
$S_{meth.}$	.40	-.49	.64	-.65	.44	-1.6	.49	-.29
$N \times P_{\frac{1}{2}}$	.76	.39	.81	.36	1.2	.50	.66	.38
$P \times P_s^{\frac{1}{2}}$	.053	.054	.056	.057	.046	.051	--	--
Ck.%N_2	-.058	-.055	-.054	-.051	-.16	-.16	--	--
Ck.%N^2	40	28	18	7.5	40	7.2	24	16
Ck.%P_2	3.2	6.4	--	--	-5.5	-1.2	4.7	7.1
Ck.%P^2	-49	-99	92	9.2	--	--	58	-5.3
Ck.%N x Ck.%P	1104	1349	--	--	--	--	961	1182
N x Ck.%N	-186	-219	-33	-8.8	--	--	-196	-219
P x Ck.%N	-.16	-.17	-.14	-.16	-.14	-.15	-.17	-.18
N x Ck.%P	.18	.17	.18	.17	.043	.028	.21	.20
P x Ck.%P	-.22	-.18	-.23	-.15	--	--	.28	.32
Ck.%N x $P_s^{\frac{1}{2}}$	-2.3	-2.3	-2.2	-2.1	--	--	-2.8	-2.8
Ck. $yield_s$	-4.9	-3.6	-3.8	-2.2	-4.1	-.54	--	--
	-.11	--	-.14	--	-.21	--	-.090	--

[a]The multiple regressions are in the same numerical order as listed in Table 31.

[b]Values less than 100 have been rounded to two significant digits.

and decreasing in the Curvilinear Complete and Curvilinear Reduced Models at the means of the associated X variates in the partial derivative. The curve reached a maximum at a soil test of about 5.5 pounds of P per acre in both models and was negative with increasing slope thereafter. In the Soil Test P and Soil Test P Reduced Models, the slopes of $\hat{Y}_3$ on soil test P level were negative and becoming less negative as shown in the preliminary investigations. The positive slope of $\hat{Y}_3$ on soil test P level in the Curvilinear Models probably was due to the correlation between the soil test P and leaf P variates which has been discussed previously.

The change in $\hat{Y}_3$ on the Check percent N level varied among the models. In the Curvilinear Complete, Curvilinear Reduced, Leaf P-I and Leaf P-I Reduced Models, the slopes were positive and increasing at the means of the X variates in the partial derivatives. However, below Check percent N values of 1.94 to 2.39%, the slopes were negative as expected. In the Soil Test P Models, the slopes of $\hat{Y}_3$ were negative and becoming more negative at the means of the X variates. However, the slope was positive and decreasing in the Soil Test P Model at Check percent N values up to 2.42% but the slope in the Soil Test P Reduced Model was negative at all relevant values of the Check percent N. These changes in $\hat{Y}_3$ on the Check percent N level, however, are influenced by the high

correlation between the Check percent N and Check percent P levels.

The slope of $\hat{Y}_3$ on the Check percent P level in all models was negative and decreasing. These effects over most of the relevant range were similar to those in the preliminary investigations.

Although the significance of some of the interaction terms on $\hat{Y}_3$ varied among the models, the signs of each of the regression coefficients of the interactions, except those of the N x Check percent P interaction, were the same in all models (Table 35). The NP interaction was positive as has been shown repeatedly. The N x soil test P interaction was positive in all models although it was positive without P and negative with P fertilizer in the preliminary investigations (Figure 27). The P x soil test P interaction was negative in all models as expected (Figure 23). Its effect was the largest in the Soil Test P Models. The Check percent N x Check percent P interaction was negative in all models. As expected (Figures 28 and 29), the N x Check percent N interaction was negative in all models. The P x Check percent N interaction was positive although in the preliminary investigations its effect was not marked (Figure 28). The differences in the signs of the N x Check percent P interaction among the models have little significance since the confidence intervals would include both positive and negative values

where the t values were less than one. This interaction which was negative only in the Leaf P Models also appeared to be negative in the preliminary investigations (Figure 26). The P x Check percent P interaction was negative in all models as indicated previously (Figure 21). The Check percent N x soil test P interaction also was negative in all models.

The small effect of the $P_{sub.}$ variate, particularly in the Soil Test P Models, was unexpected in view of its effect shown in the preliminary investigations (Figure 25). Since the $P_{sub.}$ variate was highly correlated with the leaf N and P variates (Table 26), its effect was largely accounted for by the leaf P variates in the models containing these variates. As discussed previously, the yield response to P fertilizer has varied between two broad groups of soils. With one exception, the soil test P in the subsoil was lower in the soils with higher responses than in the soils with the lower yield responses. This exception was the soils of the Carrington-Clyde Area whose soil test P in the subsoil is generally low but whose responses to P fertilizer are similar to those soils with higher levels of soil test P in the subsoil.

The availability of the P in the subsoil needs to be studied in more detail. The experiments from the Carrington-Clyde Area may be removed from the observations in this study to determine the effect of this variable on the rest of the

soils in the state where its effect appears to be more pronounced. The factors responsible for the different behavior to P fertilization in the Carrington-Clyde soils need to be determined and included in the multiple regression models. This information is particularly necessary for predicting responses to fertilizer based on soil tests. It is less necessary if the predictions are based on leaf composition since the leaf composition appears to reflect the availability of the P throughout the soil profile and from different sources within the soil.

The small effect of the $P_{meth.}$ variate in the regression equations also was unexpected. It was significantly correlated with the N fertilizer level, soil test P level in the plow-layer and subsoil, Check percent P level, most of the interactions involving these variables and the Check yield (Table 26). These significant correlations indicate that the method of P application was confounded with other variables. This confounding was discussed in the preliminary investigations in the relationship between yield and method of application. The standard errors of the partial regression coefficients for the $P_{meth.}$ variate also were large in relation to the values used for this variate.

The effect of the method of application on $\hat{Y}_3$ also needs to be determined by omitting the experiments from the Carrington-Clyde, Fayette and Fayette-Downs Areas and calcu-

lating new regressions. Corn in these areas may respond differently to the different methods of P application than corn in the rest of the state. These differences may be associated with climatic factors such as better-distributed rainfall and lower evapo-transpiration losses. The less rapid drying of the plow-layer may increase the availability of the disked-in P fertilizer. The climatic factors may be responsible for the apparently different effects of both the $P_{sub.}$ and $P_{meth.}$ variates in the soils of Northeastern Iowa. If conditions are more favorable for the utilization of disked-in P fertilizer near the surface by the corn, the corn also may utilize more of the P in the plow-layer and from organic sources and thus have less dependence on the P in the subsoil.

The maximum R^2 of the regressions of $\hat{Y}_3$ on the X variates was 70.5%. Since there have been no similar studies using several variables and data from many experiments over different soils and seasons to predict yield responses to fertilization, the precision of these regression equations cannot be compared with others. In most of the studies of yield response on a single level of a variable which have included a number of experiments on different soils and over different seasons, the linear or multiple correlation coefficients usually have been 0.5 to 0.6 (an r^2 or R^2 of 25 to 36%).

Additional research on the data in this study may increase the precision in estimating the yield responses. The estimated changes in yield from the regression equation for all observations should be compared with the actual yield responses since the deviations may indicate how the precision of the yield predictions may be improved. The standard errors of the regression coefficients also need to be studied to determine the sources of the deviations not explained by regression.

Many of the figures in the preliminary investigations indicated the presence of three-factor interactions among N and P fertilizer and the soil test P, Check percent N and Check percent P levels and interaction terms involving components other than linear x linear terms. The added reduction in the residual error due to addition of these variates should be determined. Some of the variables such as the soil test P in the subsoil and the Check yield should be included as curvilinear functions. Stand x fertilizer level interactions and Check yield x fertilizer level interactions also should be included in any additional studies. Since the soil test P variates added to the Leaf P Models increased the R^2 about 2%, the addition of soil test N variates may give a similar increase in the precision. The addition of K fertilizer, soil test K and leaf K variables plus all of their interactions with the other variables will increase markedly

the practical value of the yield response equations although the precision may not be increased greatly.

The addition of climatic variables should give a considerable gain in the precision. The use of these variables will allow all of the data to be included and will help to predict yield responses to fertilizer for various moisture conditions based on probabilities of occurrence. From the number of additional variates that may be added to the regression models and the studies needed on some of the variates that were included, it is apparent that this research is only in the preliminary stages.

Economic analyses may be applied to the yield response functions developed in this study to determine the economic optima of corn fertilization with N and P fertilizers at any N and P leaf composition level, soil test P level and stand level. If the soil test N values had been available and included, the economic analyses of a soil test model could have been made and adapted for immediate use. However, the theory of the economic analyses may be extended by using the N and P contents in the corn leaf as estimates of the availability of the N and P in the soil.

The major objective of recent fertilizer research has been to determine the yield functions of two or three variable nutrients so that the economic optima of fertilizer use may be determined. The number of these experiments, however, has

been few. The utilization of these few experiments in the economic decisions involving fertilizer use for a wide range of conditions thus becomes of interest. Since many fertiliser experiments have been conducted in Iowa in the last decade, the data from these may be combined with the economic studies to determine the yield functions for a wider range of conditions. Since most of the fertilizer experiments had low to medium rates of two or three nutrients and quite often only two levels of the nutrients, some have thought that they are of little value in determining the economics of fertilization. The results of this study may be used to test this concept.

Another method of combining the fertilizer experiments designed for economic studies is to consider also the availability of the nutrients in the soil. A generalized yield function has been projected with individual experiments being considered a part of this yield function. Jensen (42) has reviewed the literature on this concept and has extended the theory for a generalized yield function based on the estimated nutrient levels in the soil and the nutrients applied. There has been considerable discussion about this approach and some research is in progress but little has been published to date.

Many experiments were combined in this study by multiple regression analysis with the assumption that all were a part of a general yield response function. It was also assumed that the relationship of the individual experiments to the

general yield response function could be defined by the availability of the N and P in the soil as indicated by leaf composition and soil test levels, by the interactions among fertilizer, leaf composition and soil test levels and by miscellaneous factors such as stand level and Check yield. Since the yield responses of the various fertilizer treatments were calculated from the Check yield, any error in the estimation of the Check yield affected all of the yield responses in an experiment. However, these errors should be normally and independently distributed in the large number of experiments and thus should not introduce any bias. These errors will increase the residual error, but in view of the high R^2 of these regressions and with the chance of further reduction of the residual error by adding other X variates, the errors in the yield responses due to the method by which they were calculated do not appear to be large.

A limitation in the data used in this study was the unequal frequency of the observations of the X variates throughout the relevant ranges. The levels of N and P fertilizer were concentrated in the low to medium ranges. The leaf composition data were concentrated in the medium to high levels with too few observations in the very low to low levels. Too few observations also occurred at the higher stand levels. The relevant ranges of the X variates should be considered in

using the regression equations. These and the means of the X variates are given in Table 27.

The yield response regression equations need to be checked against the experiments with a wide range in fertilizer levels to determine how well they predict the yield responses. For example, in the corn experiment reported by Heady et al. (39), the estimated yield responses due to 80, 160, 240 and 320 pounds each of N and P_2O_5 were 55.7, 93.7, 119.4 and 132.2 bushels per acre, respectively. These estimates from the Curvilinear Complete Model are increases above the Check yield of 15.4 bushels per acre. The predicted yield responses from the yield function derived by Heady et al. (39) were 101.6, 125.3, 136.1 and 140.4 bushels for the same treatments based on the predicted Check yield of -5.7 bushels per acre. The yield responses estimated from the regression equation in this study, at least at the lower levels, are much more reasonable for economic planning than those estimated from the yield function derived from this experiment.

The rates of N and P_2O_5 that gave a zero yield response, or maximum yield, in this same experiment were estimated from the Curvilinear Complete Model to be 405 pounds of N and 350 pounds of P_2O_5. From their yield function, Heady et al. (39) predicted that the maximum yield occurred at 398 pounds of N and 337 pounds of P_2O_5. Since the maximum fertilizer levels

in this study were 180 pounds of N and 160 pounds of P_2O_5, the estimated yield responses beyond the relevant ranges appear to be reasonable.

Since corn leaf composition has never been used to predict responses to fertilizer, further research is needed to determine the validity of these yield response regression equations. Although the maximum R^2 was 70%, the yield response predictions need to be checked over a wide range of conditions to determine if the equation applies to the population with equal precision and to determine the extent of the bias in the yield estimates. This can be done by using a few fertilizer treatments on many locations for several years and by selecting the X variates to cover the relevant ranges. The yield responses predicted from the leaf composition and other variates thus can be compared with the actual yield responses to determine the R^2 of these yield response functions. This study also will help to determine on which soils the prediction equations are most suitable and will give information where further improvements or refinements are needed most.

Since the leaf composition of the corn in one year may be used to predict the yield responses to fertilization in the next several years, the precision of the predicted yield responses one or more years later also needs to be determined. This brings up the problem of studying the year-to-year vari-

ations in the leaf composition to determine how they affect the precision of the yield response predictions. The P and K composition may be relatively constant in the same field from year to year but the N composition will vary with management practices. In this respect, the use of the N composition in the leaf will be no different from the use of N soil tests. For a given soil test N level, the recommended rates of N must be adjusted for recent legume crops, manure, N residual effects, crop sequence and management level. These same factors also must be considered in recommending rates of N fertilizer in the succeeding years from the leaf N data.

The final problem in using the corn leaf composition is to predict the responses of other crops in the rotation to fertilizer. This presents no complex problem since the relationship between the profitable fertilization of corn and that of the other crops in the rotation is fairly well established.

5. Yield

Regressions of the corn yield at any level of N and P fertilization (Y_4) on selected X variates were determined for four multiple regression models (Table 36). The curvilinear multiple regression model (Curvilinear Complete Model) included 17 X variates. In the linear multiple regression model (Linear Complete Model), the squared variates in the curvilinear functions of six variables were deleted to determine the value

Table 36. Multiple regression statistics for the multiple regression models of the corn yield (Y_4) on selected X variates

Model	Variate	Equation $\hat{Y}_4 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level[a]
Curvilinear Complete		-255.2[b]			
	N	$-0.05115\ X_1$	0.05870	0.87	0.38
	N^2	$-0.000319\ X_2$	0.000244	1.31	0.19
	P	$+0.2798\ X_3$	0.07935	3.53	**
	P^2	$-0.000780\ X_4$	0.000453	1.72	0.09
	NP	$+0.000561\ X_5$	0.000305	1.84	0.07
	$P_s^{\frac{1}{2}}$	$-5.310\ X_6$	5.572	0.95	0.34
	P_s	$+1.798\ X_7$	1.192	1.51	0.14
	$P_{sub.}$	$+0.1238\ X_8$	0.08470	1.46	0.15
	S	$+12.06\ X_9$	2.482	4.86	**
	S^2	$-0.3173\ X_{10}$	0.09094	3.49	**
	$N \times P_s^{\frac{1}{2}}$	$+0.04601\ X_{11}$	0.02333	1.97	*
	$P \times P_s^{\frac{1}{2}}$	$-0.07110\ X_{12}$	0.02794	2.54	*
	%N	$+104.4\ X_{13}$	16.20	6.45	**
	$\%N^2$	$-22.27\ X_{14}$	4.428	5.03	**
	%P	$+543.6\ X_{15}$	112.0	4.85	**
	$\%P^2$	$-1326.3\ X_{16}$	266.0	4.99	**
	%N x %P	$+104.2\ X_{17}$	57.66	1.81	0.08

[a]Significance probability level.

[b]This is a, the constant in the regression equation.

Table 36. (Continued)

Model	Variate	Equation $\hat{Y}_4 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level
Linear		-189.7^b			
Complete	N	$-0.1198\ X_1$	0.04892	2.45	*
	P	$+0.2698\ X_3$	0.05642	4.78	**
	NP	$+0.000323\ X_5$	0.000284	1.14	0.26
	$P_s^{\frac{1}{2}}$	$+2.868\ X_6$	1.782	1.61	0.11
	$P_{sub.}$	$+0.2029\ X_8$	0.08815	2.30	*
	S	$+3.310\ X_9$	0.3048	10.86	**
	$N \times P_s^{\frac{1}{2}}$	$+0.06137\ X_{11}$	0.02376	2.58	**
	$P \times P_s^{\frac{1}{2}}$	$-0.09469\ X_{12}$	0.02641	3.59	**
	%N	$+74.13\ X_{13}$	7.627	9.72	**
	%P	$+682.9\ X_{15}$	80.03	8.53	**
	%N x %P	$-215.2\ X_{17}$	30.32	7.10	**
Curvilinear		-244.4^b			
Leaf	S	$+11.16\ X_9$	2.511	4.45	**
	S^2	$-0.3023\ X_{10}$	0.09195	3.29	**
	%N	$+93.11\ X_{13}$	15.57	5.98	**
	$\%N^2$	$-24.06\ X_{14}$	4.414	5.45	**
	%P	$+641.0\ X_{15}$	108.1	5.93	**
	$\%P^2$	$-1763.2\ X_{16}$	244.3	7.22	**
	%N x %P	$+174.1\ X_{17}$	56.92	3.06	**
Linear		-179.9^b			
Leaf	S	$+3.354\ X_9$	0.3141	10.68	**

Table 36. (Continued)

Model	Variate	Equation $\hat{Y}_4 = a + \sum b_i X_i$	$s(b_i)$	t	Sign. level
Leaf					
	%N	$+67.72\ X_{13}$	7.743	8.75	**
	%P	$+715.7\ X_{15}$	81.57	8.77	**
	%N x %P	$-202.6\ X_{17}$	31.15	6.50	**

of the curvilinear functions. In both of these models, the $P_{meth.}$ variate was deleted according to Snedecor (74) because its effect appeared to be confounded with other factors not included in the models. The deletion of this variate decreased the R^2 of the Curvilinear and Linear Complete Models by 1.6 and 2.4%, respectively (Tables 22 and 37).

Table 37. Analyses of variance for the multiple regression models of the yield (Y_4) on selected X variates

Model	Source of variation	d.f.	S.S.	M.S.	F	R	R^2
Curvilinear Complete	Regression	17	189395	11141	50**	.7790	.6068
	Error	556	122705	221			
Linear Complete	Regression	11	174788	15890	65**	.7484	.5600
	Error	562	137311	244			
Curvilinear Leaf	Regression	7	179142	25592	109**	.7576	.5740
	Error	566	132957	235			
Linear Leaf	Regression	4	162175	40544	154**	.7209	.5196
	Error	569	149924	263			

In the other two models, all of the variates were deleted except those for stand level and the N and P leaf composition. The stand level was included since it can be determined easily at the time of leaf sampling. The curvilinear multiple regression model (Curvilinear Leaf Model) included seven X variates and the linear multiple regression model (Linear Leaf Model) included four X variates (Table 36).

The regression of yield on the X variates was highly significant in all models with the R^2 varying from 0.520 to 0.607 among the models (Table 37). The added reduction in the residual error by including three variates for curvilinear functions in the Curvilinear Leaf Model and six variates in the Curvilinear Complete Model was highly significant in both cases (Table 38). The increase in the R^2 was 4.7% for the six curvilinear variates in the Curvilinear Complete Model and 5.4% for the three variates in the Curvilinear Leaf Model. Most of the gain from the curvilinear functions appeared to be due to those of the stand level and leaf N and P variables.

Although the R^2 of the Leaf Models were within 3.3 to 4.0% of those of the Complete Models, the added reduction in the residual error due to the additional variates was highly significant in both the Curvilinear and Linear Complete Models (Table 38). Since the maximum r^2 of yield on a single variate was 0.367 (Table 39), the additional variates in the multiple

Table 38. Analyses of variance of the reduction in the residual error due to curvilinear variates and variates in addition to the leaf and stand level variates in the multiple regressions of the yield (Y_4) on selected X variates

Models	Source of variation	d.f.	S.S.	M.S.	F
Curvilinear Complete vs. Linear Complete	Regression on 11 variates	11	174788		
	Added reduction by 6 curvilinear variates	6	14607	2434	11.0**
	Error	556	122705	221	
Curvilinear Leaf vs. Linear Leaf	Regression on 4 variates	4	162175		
	Added reduction by 3 curvilinear variates	3	16967	5656	24.1**
	Error	566	132957	235	
Curvilinear Complete vs. Curvilinear Leaf	Regression on 7 variates	7	179142		
	Added reduction by 10 variates other than leaf and stand	10	10253	1025	4.6**
	Error	556	122705	221	
Linear Complete vs. Linear Leaf	Regression on 4 variates	4	162175		
	Added reduction by 7 variates other than leaf and stand	7	12613	1802	7.4**
	Error	562	137311	244	

regression gave a considerable increase in the precision in estimating yield.

The significance level of the partial regression coefficients (Table 36) varied widely in the Curvilinear Complete Model with the N and $P_s^{\frac{1}{2}}$ variates having t values less than one. They should be retained in the regression equation, however. In the Linear Complete Model, the partial regression coefficients were significant at the 0.26 level or less. All

Table 39. Linear correlation coefficients (r) between the X variates associated with the yield (Y_4) and between the X variates and Y_4

X variate	X variate								
	N^2	P	P^2	NP	$P_s^{\frac{1}{2}}$	P_s	$P_{sub.}$	S	S^2
N_2	.92[a]	.23	.32	.70	.04	.03	-.06	-.01	-.01
N^2	1.00	.28	.38	.73	.01	.01	-.09	.00	.00
P_2		1.00	.93	.65	-.04	-.04	-.16	.01	.00
P^2			1.00	.74	-.05	-.04	-.16	.03	.03
$NP_{\frac{1}{2}}$				1.00	.02	.01	-.11	.01	.01
$P_s^{\frac{1}{2}}$					1.00	.98	.10	-.02	-.02
P_s						1.00	.09	-.03	-.02
$P_{sub.}$							1.00	.05	.04
$S_{sub.}$								1.00	.993
S^2									1.00

	X variate							
	$N \times P_s^{\frac{1}{2}}$	$P \times P_s^{\frac{1}{2}}$	%N	$\%N^2$	%P	$\%P^2$	%N x %P	Yield (Y_4)
N_2	.93	.24	.27	.25	.14	.14	.21	.21
N^2	.84	.27	.20	.20	.14	.14	.19	.17
P_2	.21	.90	-.03	-.03	.32	.31	.19	.25
P^2	.29	.82	-.03	-.02	.27	.28	.17	.21
$NP_{\frac{1}{2}}$	.65	.62	.15	.15	.28	.27	.25	.28
$P_s^{\frac{1}{2}}$	.29	.27	.10	.10	.29	.27	.23	.17
P_s	.27	.26	.06	.06	.25	.23	.18	.15
$P_{sub.}$	-.03	-.11	.14	.14	.24	.24	.23	.16
$S_{sub.}$	-.03	-.03	-.12	-.11	-.01	-.01	-.06	.26
S^2	-.03	-.03	-.14	-.13	-.03	-.02	-.08	.23
$N \times P_s^{\frac{1}{2}}$	1.00	.31	.30	.30	.22	.21	.28	.27
$P \times P_s^{\frac{1}{2}}$		1.00	.02	.02	.35	.35	.24	.25
$\%N_2$			1.00	.994	.56	.53	.84	.51
$\%N^2$				1.00	.55	.53	.84	.49
$\%P_2$					1.00	.99	.91	.59
$\%P^2$						1.00	.90	.54
%N x %P							1.00	.61

[a]Number of observations = 574. Values of r larger than 0.084 and 0.110 are significant at the 5% and 1% levels, respectively.

regression coefficients were significant at the 0.01 level or less in the Curvilinear and Linear Leaf Models.

The change in the estimated yield on N fertilizer, P fertilizer, stand, percent N and percent P levels in the Curvilinear Complete Model was positive and decreasing at the means of the other variates in the partial derivatives. The slope of $\hat{Y}_4$ on stand, percent N and percent P levels was also positive and decreasing in the Curvilinear Leaf Model. The slope of $\hat{Y}_4$ appeared to be positive over most of the relevant ranges of these variables. These effects also were shown in the preliminary investigations (Figures 22, 30, 31, 32 and 34). Although the regression coefficients of both of the N fertilizer variates were negative in the Curvilinear Complete Model, the slope of $\hat{Y}_4$ on N level was positive due to the influence of the NP and N x $P_s^{\frac{1}{2}}$ interaction variates. Since N and P levels were highly correlated with the percent N and percent P levels (Table 39), part of the fertilizer effect on yield also will be reflected by the leaf composition variates which have a dominant effect in these regressions.

The slope of $\hat{Y}_4$ on the soil test P level in the Curvilinear Complete Model was negative and decreasing at the means of the X variates in the partial derivative. This effect, contrary to the relationship in the preliminary investigations (Figure 33), has been observed before when both soil test P and leaf P variates were present. It probably is due to the

correlation between the soil test P and percent P in the leaf (Table 39), both of which indicate the availability of the P in the soil.

The NP, N x soil test P and P x soil test P interactions appear to be exerting similar effects on yield as were determined in the preliminary investigations (Figures 23, 27 and 33). The variate whose effect differed the most among the models was the percent N x percent P interaction whose partial regression coefficient was negative in the Linear Models and positive in the Curvilinear Models. In the Linear Models, this negative interaction forces the slope of the estimated yield curve to decrease with increasing levels of leaf N and P; the yield thus becomes a curvilinear function of the leaf N and P levels. Since the linear correlation between the percent N and percent P is high ($r = 0.56$, Table 39), the percent N x percent P interaction has, in part, the characteristics of a squared term in a quadratic function. In the Curvilinear Models, the percent N x percent P interaction was positive as expected in its relationship with the curvilinear function of both variables.

The maximum percentage of the yield variations accounted for by regression on the X variates was 60.7%. An additional 1.6% was gained by including the variate for the method of P application but it was confounded with fall plowing, soil area and climatic factors. Another variable that should be in-

cluded, although there was little indication of its importance in these data (Figure 34), is the fertilizer x stand level interaction. The N and P availability in the soil x stand level interactions also may significantly increase the precision of the yield prediction. Including K fertilizer, soil test K and leaf K levels and their interactions with the other variables will increase markedly the usefulness of the yield prediction equation although the effect of increasing the R^2 above the present level may not be large. The largest gain in the precision in the yield prediction will come from the addition of climatic variables since they are a large source of variation in corn yields. The addition of all of these variables into a curvilinear multiple regression equation could double to triple the number of X variates and, of course, increase markedly the computational problems and the time and cost of obtaining the regression equations.

6. Critical levels, nutrient balance and luxury consumption

The relationships of the estimated yield to the N and P concentrations in the corn leaf were determined from the curvilinear multiple regression equations in order to study the critical N and P levels, nutrient balance and luxury consumption. These relationships were calculated from the regression statistics of the Curvilinear Leaf Model (Table 36). The estimated yield was a curvilinear function of the stand,

percent N and percent P levels and also was a function of the percent N x percent P interaction; all variates in the equation gave a highly significant reduction in the residual error.

The partial derivatives of $\hat{Y}_4$ with respect to the percent N and percent P levels were first calculated as follows:

$$\frac{\partial \hat{Y}_4}{\partial \%N} = 93.11 - 48.12\%N + 174.1\%P \text{ and}$$

$$\frac{\partial \hat{Y}_4}{\partial \%P} = 641.0 - 3526.4\%P + 174.1\%N \ .$$

Hence, the slope of $\hat{Y}_4$ on the percent N level varied not only with the percent N level but also with the percent P level because of the significant interaction between the two. Likewise, the slope of $\hat{Y}_4$ on the percent P level varied with both the leaf N and P levels.

The N and P concentrations in the leaf at maximum yield were determined by setting the partial derivatives equal to zero and solving the two simultaneous equations. The N and P percentages at the maximum yield were 3.16 and 0.338%, respectively. The partial derivative of $\hat{Y}_4$ with respect to stand level indicated that the maximum yield occurred at a stand of 17.42 (17,420 stalks per acre). Substituting the stand, percent N and percent P values at maximum yield into the regression equation of the Curvilinear Leaf Model, the maximum yield was found to be 113.5 bushels per acre. The

relationships between the percent N and percent P in the corn leaf at 75, 90, 95 and 97% of the maximum yield or 85.1, 102.2, 107.8 and 110.1 bushels per acre, respectively, were then calculated from the regression equation. For each yield level, the stand level value at the maximum yield was substituted for the stand level variates and the percent N values were determined by substituting in successive values for the percent P variates and solving the quadratic equations.

For the Curvilinear Complete Model (Table 36), the stand level, percent N and percent P at maximum yield were calculated in a similar manner and were found to be 19,000 stalks per acre, 3.11% N and 0.327%P. The maximum yield at the above values of the stand, percent N and percent P levels and at the mean levels of the other variates in the regression equation was also 113.5 bushels per acre. Hence, the relationship of yield with the leaf N and P levels in the Curvilinear Complete Model was similar to that in the Curvilinear Leaf Model.

The relationships between the N and P concentrations in the leaf at the five yield levels, as derived from the Curvilinear Leaf Model, are shown in Figure 35. The figure is analogous in most respects to the "contour maps" of the fertilizer-crop response relationships presented by Heady et al. (39). The isoquants (lines connecting points of equal yield) for yield levels below the maximum show that equal yields may

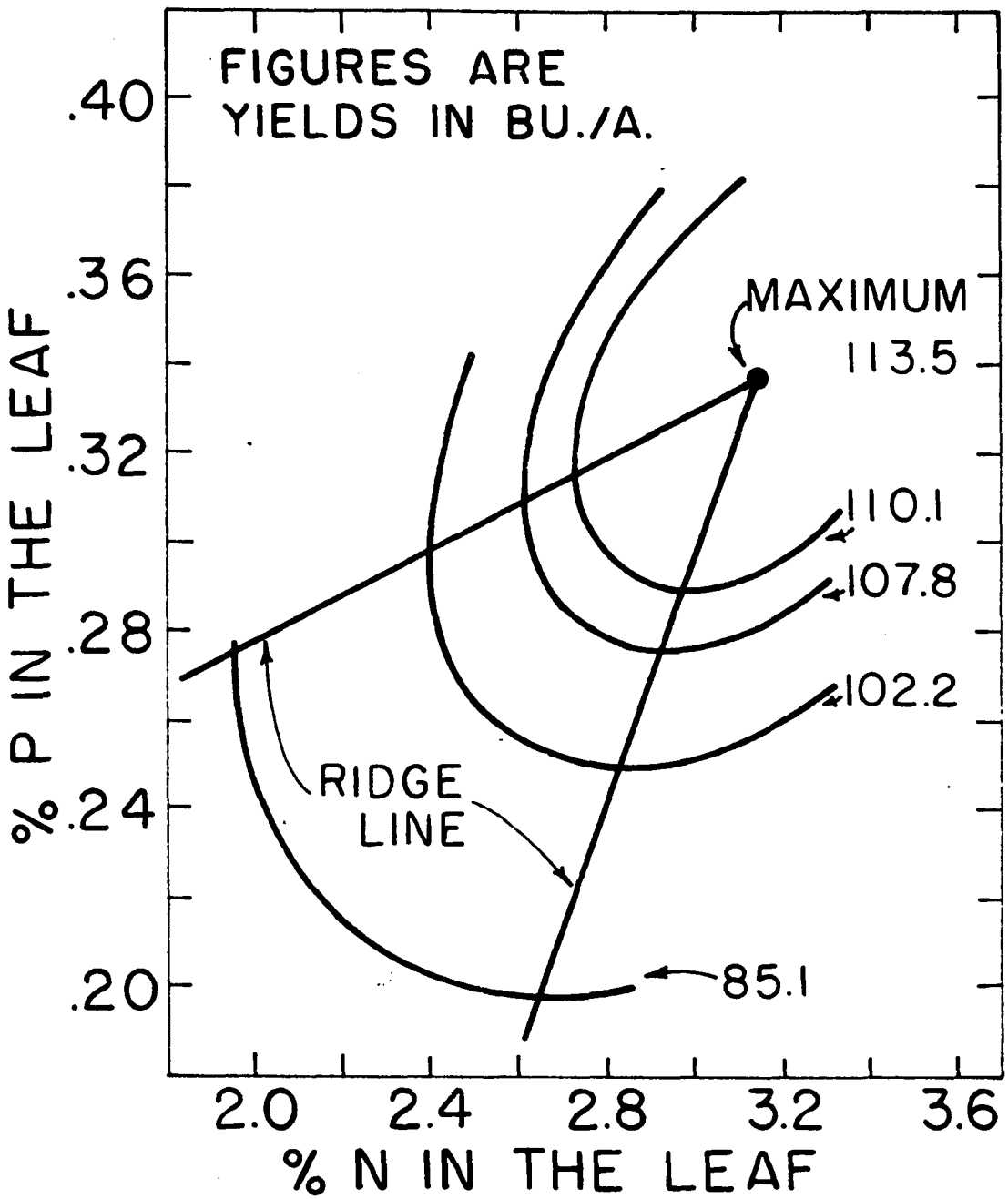

Figure 35. Yield isoquants for 75, 90, 95 and 97% of the maximum yield, i.e., 85.1, 102.2, 107.8 and 110.1 bushels per acre, respectively, showing combinations of N and P concentrations in the corn leaf for the specified estimated yields (ends of the curves give the limits in the observations)

occur for widely varying ratios of N and P in the corn leaf. The isoquant at the maximum yield reduces to a point; only at the maximum yield is the ratio of the percent N and percent P constant. Along any isoquant, the rate of substitution of the percent N for percent P occurs at a diminishing rate within the ridge lines. The ridge lines connect the points on the isoquants having zero rates of substitution. Since the area between the ridge lines is considered the "rational" area in fertilizer use, this area is also designated the "rational" area for the N and P concentrations in the leaf. However, the relevant ranges of the observations of the N and P contents in the leaf extend considerably beyond the ridge lines into the area which is designated the "irrational" area.

This concept of the relationship of yield to the percent N and percent P levels appears to verify the economic approach to the yield response functions of fertilization developed by Heady et al. (39). They expressed nutrient combinations in terms of their substitution or replacement rates since similar yield increases could be obtained with different combinations. However, they were not certain whether N, P and K could substitute for each other in the chemical processes of the plant or that the terms substitution or replacement rates represented an entirely accurate physiological concept. The results from this study appear to verify their approach as being logically and physiologically correct. Since the

concentrations of N and P in the leaf may vary for any given yield level below the maximum yield, substitution of one for the other thus appears to occur, at least indirectly, in the physiological processes in the plant.

This concept of the yield-nutrient concentration relationship, as outlined here, affects markedly the prevailing concepts on critical nutrient percentages or levels, nutrient balance and luxury consumption of nutrients. The critical nutrient percentage has been defined several ways. Macy (52) defined it as the transition from the "poverty adjustment" to the "luxury consumption" region, a sharp point in his method of expressing the yield-nutrient concentration relationship. Ulrich (85) defined the critical nutrient concentration as that narrow range of concentrations at which growth rate or yield first begins to decrease in comparison to plants at a higher nutrient level. Others including Tyner (81) have defined it as that concentration which is just adequate for maximum growth. He first proposed tentative critical levels in the corn leaf of 2.9% N and 0.295% P. Recently, Tyner et al. (82) stated that these levels had been established definitely although there has been no research published to that effect. Bennett et al. (4) assumed that the critical levels were approximately attained at 95% of the maximum yield and found that the critical N level varied from 2.6 to 3.1% in individual experiments. They questioned wheth-

er a definite critical level of N existed. A more practical concept of the critical percentage is that level in the plant below which fertilization is profitable. However, this level will vary with different crop:fertilizer and nutrient:nutrient price ratios.

The relationships in Figure 35 illustrate the first difficulty in defining a critical nutrient level. As is characteristic of yield response functions, the rate of change in the slope of the estimated yield on the percent N and percent P levels decreases more slowly as the maximum yield is approached. Hence, there is a broad range in the percent N and percent P values from the maximum yield to 97 or 95% of the maximum yield. The second difficulty in defining the critical level is that the level of the percent N for a given percentage of maximum yield varies with the level of the percent P in the leaf. For example, along the 110.1 bushel isoquant (97% of maximum yield) and within the rational area, the critical percentage of N increases from 2.74 to 2.99% as the critical percentage of P decreases from 0.315 to 0.290%. If the percentage of one of the nutrients is held constant at a lower level and the percentage of the other varied, the critical percentage and the maximum yield occur at lower levels. For example, if the percent P is held constant at 0.25% and the percent N is increased above 2.0%, the yield will be increased from 85 bushels to a maximum of 102 bushels.

The maximum yield occurs at the intersection of the given percent P level and the ridge line and at a N percentage of 2.84%. The N level at 97% of this 102 bushel maximum yield thus will be considerably lower and about 2.6%.

In the determination of the critical percentages, one nutrient has been varied and the others have been held at high and constant levels in practically all experiments. Only Lundegårdh (49) considered that the critical level of one nutrient, and the yield responses to be expected from addition of this nutrient, varied with levels of other nutrients. He used an "interference factor", but at only three discrete levels, in his yield response equations to compensate for the level of a second nutrient. Pfeiffer et al. (62) and Macy (52) claimed that the critical percentages were largely independent of the levels of other growth factors. Ulrich (86) found that the relationship between yield and concentration varied with the level of the second nutrient in pot culture studies and also recognized that critical levels were influenced by soil, climate, stage of development and other nutrients. However, he did not believe that the effects of these factors were large enough to alter interpretation of critical levels under field conditions. The results from this study appear to be ample evidence to question the concepts of Macy (52), Ulrich (84, 86 and 87) and Tyner (81) who have considered the critical level as a point or a narrow range of

values. Their concepts appear to be only a special case in the general relationship between yield and nutrient concentration. This special case is that the critical nutrient level becomes a sharply-defined point or narrow range of values only at or very near to the maximum yield and all other factors must be at their appropriate values to give this maximum yield. Any change in the value of any other factor thus changes the maximum yield and the critical level of the nutrient in question.

This concept of the relationship of yield to the N and P leaf levels may be extended to include all other factors which have significant interactions with the N and P leaf composition. The data in Table 1 show that yield is a function of the percent P x percent K interaction and probably is also a function of the percent N x percent K interaction. Stand level also may enter into these relationships although its interactions with leaf N or P levels were not included in these yield regressions. Nicholson and Pesek[1], Spies (75) and Ellis _et al_. (27) reported that the critical N level was lowered by moisture deficiency. Hence, the critical nutrient level appears to include a wide range of values depending how it is defined and upon levels of all other factors which have interactions with the specified nutrient. It also appears

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[1]Nicholson, R. P. and Pesek, J. T. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1957.

that the term "critical percentage or level" is a misnomer; some other term should be used in referring to these nutrient levels.

The area and isoquants outside of the area bounded by the ridge lines in Figure 35 appear to be of agronomic and economic interest. Although the leaf N and P levels of the majority of the observations fell within the rational area, about 11% occurred above and 20% occurred to the right of this area. In the yield-leaf composition relationship determined from the Curvilinear Complete Model, the distribution of the observations on both sides of the rational area appeared to be about equal. Most of the observations in the irrational area fell in the zone between 90% of maximum yield and the maximum yield.

If the yield relationships with the leaf N and P levels in the irrational area behave as shown by the isoquants, i.e. the marginal rate of substitution is positive, the effect of fertilization of corn whose leaf N and P contents lie in this irrational area may be quite different from fertilization of corn in the rational area. For example, if the N and P concentration of the leaf lies beyond the right ridge line, application of N fertilizer which increases the N content but has no effect on the P content will decrease the yield. If the N fertilizer increases the N content and the P content slightly or if rates of both N and P fertilizer increase the

leaf N and P contents to the extent that the levels of each remain on the same isoquant, there will be no change in yield. If P fertilizer increases the leaf P content, the yield will be increased and it will be increased somewhat more if there is also a slight decrease in the leaf N level. Further investigation of the fertilization of corn whose Check percent N and P contents lie in the irrational area is needed.

The relationship of yield to leaf N and P levels (Figure 35) also applies to the concepts on nutrient balance. The balance between the N and P contents in the leaf appears to be critical only at yields near the maximum and becomes less critical as the yield decreases. Within the rational area, the N-P balance cannot be upset easily by moderate fertilization. However, in the irrational area which may be considered an area of unbalance, fertilization with the nutrient not in short supply may cause a further unbalance and a yield decrease. For yields near the maximum, the conclusions of Shear et al. (72) on nutrient balance appear to be reasonable. From many factorial experiments of 2 to 5 elements at 3 to 5 levels on tung trees in sand cultures, they concluded that plant growth was a function of intensity and balance as reflected in the leaf composition of plants, that the concentration of all mineral elements in the leaves must be considered and that leaf composition was the only valid criterion of the nutritional status of the plant.

The presence of observations outside of the ridge lines or in the irrational area also applies to the present concept of the luxury consumption of nutrients by plants. It has been defined by Macy (52) as the zone above the critical level where nutrient concentration is increased with no change in yield. As with most critical level determinations, the luxury consumption has been defined under conditions of one variable with all others at a high and constant level. Hence, it always has been associated with high concentrations in the plant. A different concept may be that luxury consumption occurs whenever N and P levels occur in the irrational area. As shown in Figure 35, luxury consumption of N occurs primarily in the area to the right of the lower ridge line and that of P occurs primarily in the area above the upper ridge line. A term such as "irrational consumption" may be more appropriate since the same yield could be obtained with a lower content of both nutrients by moving along the isoquant from the irrational area toward the nearest ridge line.

These concepts developed here may have a far-reaching effect in many soil fertility problems and in the interpretation of critical levels, nutrient balance and luxury consumption. The development of the concepts was possible only by studying yield as a function of two plant-composition variables and their interaction. The concepts may be extended to additional variables which affect the nutrient concentration

in the plant. They need to be tested thoroughly, however, to determine if they can be accepted over a wide range of conditions.

V. SUMMARY AND CONCLUSIONS

The objectives of this study were to determine the relationships of N and P fertilizer levels, N and P composition in the corn leaf, soil test P levels and other factors to the change in the percent P in the corn leaf due to N and P fertilization, the percent P in the corn leaf at any N and P fertilizer level, the change in corn yield due to N and P fertilization and the corn yield at any N and P fertilizer level. Multiple curvilinear regression analyses were used to characterize these relationships quantitatively.

Yields, leaf composition and soil test results were available from 120 fertilizer experiments conducted on various soil types from 1948 to and including 1956. Most of the experiments were NP, NPK and PK factorials. Leaf samples from each plot were usually taken within 10 days of the 75% silking date and analyzed for total N, P and K. The data for the yields and leaf composition used in this study were treatment means.

From the 120 experiments, the yields and leaf composition of only the N and P fertilizer treatments were selected to meet the following restrictions: the K level was adequate in most cases, drouth or insect damage was not seriously limiting yields and only broadcast treatments without hill or row fertilizer were used. The data were selected on these bases because the relationship between the yield and leaf composition was affected by K deficiency, drouth or insect damage and

presence of hill or row fertilizer and variables for these factors were not included in the regression analyses. The data from 93 experiments were included in the regression analyses.

The data were examined to determine which variables and their interactions should be included in the mathematical models for regression analyses. Linear correlation coefficients and regression equations were calculated for many of the relationships. Many of these were determined without and with N or P fertilizer and the differences between or among the regression coefficients were tested for significance to determine the nature and extent of the interactions. The linear relationships were graphed and the approximate deviations from linearity were estimated by plotting the successive group means of the observations. These procedures were followed for all of the dependent variables: change in percent P, percent P, change in yield and yield.

The change in the leaf P level due to P fertilizer was highly correlated with the leaf P level, soil test P level, P fertilizer level, leaf N level and the method of P application. Most of the relationships appeared to be curvilinear. The positive NP fertilizer interaction was most striking in all relationships. Others affecting the change in the percent P due to P fertilizer were N x leaf P level, P x leaf P level,

N x soil test P level, P x soil test P level and N x leaf N level interactions.

The change in the percent P due to N fertilizer, an occurrence which has been reported in the literature and has been of interest recently, was highly correlated with the leaf P and N levels, soil test P levels, yield response to N fertilizer and the N and P fertilizer levels. This change in percent P was also affected by NP, P x leaf P, P x leaf N and P x soil test interactions. A frequency distribution of the observations showed that decreases, no changes or increases in the percent P due to N fertilizer occurred, depending upon the levels of the several factors listed. Increases occurred more frequently and were more marked in the presence than in the absence of P fertilizer. The effect of N fertilizer on the percent P was found to be different among various soils; these differences in most soils were believed to be due to differences in the soil test P levels in their subsoils.

The factors that might be used to predict the percent P, which includes the initial level plus any change due to N and P fertilizer, were also investigated. The percent P was significantly correlated with the soil test P in the plow-layer and subsoil, the percent N in the leaf and many of the factors associated with the change in percent P. There was no significant relationship with stand level.

The change in yield due to P fertilization was significantly correlated with the same factors that were correlated with the change in the percent P. Many of these relationships appeared to be curvilinear. Since there was a high linear correlation between the yield response and change in percent P due to P fertilizer and between the yield response and change in percent N due to N fertilizer, any factor which significantly affected the yield response also affected the change in the leaf composition. The change in yield due to N fertilizer was significantly correlated with the leaf P, soil test P, leaf N and N fertilizer levels. The response to N was also influenced by significant NP, P x leaf P, P x soil test P, P x leaf N and N x leaf N interactions. Where methods of P application were compared, plowed-under application gave larger increases than disked-in applications.

Comparison of leaf analysis and soil test P methods for predicting the corn yield response to P fertilizer indicated that the r^2, fraction of variations explained by regression, was almost twice as high in the regression of yield response on the leaf P levels as that of the yield response on the soil test P levels. In the comparison of the prediction of the yield response to N fertilizer on the leaf N levels in this study with the yield response on soil test N levels in another study using much of the same data, the leaf analysis method appeared to have a higher precision, particularly at

the higher levels of the N fertilizer. Since soil test N data were not available for all experiments, this variable was not included in this study.

The factors that might be used to predict the corn yield at any N and P fertilizer level were also investigated. The yield was significantly correlated with leaf N and P, soil test P, stand and N and P fertilizer levels and was also a function of the NP, N x soil test P, P x soil test P and the leaf N x leaf P interactions. The yield was most highly correlated with the leaf N and P levels since they reflected both the availability of N and P in the soil and the effect of the N and P fertilizers.

The variables that were included in the multiple regression models for each of the dependent variates were determined from the preliminary investigations. Most of the variables were included as curvilinear functions and the two-factor interactions were included as linear x linear terms.

Two forms of the quadratic function to express the curvilinear relationships were investigated. These were the quadratic equation with squared terms and the square root transformation of a quadratic equation. The single-variable square root transformation and quadratic functions were compared for all variables; the R^2 of the two functions were similar for all except for the soil test P variable whose square root function had a higher R^2 than the quadratic function. In the

regression of yield on selected X variates, four variables and associated interactions were included in one model as square root functions and in another model as quadratic functions. There was no difference in the R^2 of the two regression equations. For all of the multiple regression models, all variables whose effects were believed to be curvilinear were included as quadratic functions except the soil test P variable which was included as a square root function.

The sums of squares and cross products of the X and Y variates and the correlation coefficients were calculated by the IBM 650 Computer. From the matrix of the sums of squares and cross products of the selected variates, the inverse matrix was calculated by the IBM 650 Computer, from which were obtained the partial regression coefficients and the c_{ii} values for calculation of the standard errors.

For the regression of the change in percent P on selected X variates, the regression statistics of five multiple regression models were determined. The Curvilinear Model included 22 X variates, the Linear Model had five variates for the squared terms of the curvilinear functions deleted, the Soil Test P Model had the five leaf P variates deleted, the Leaf P Model had five variates associated with the soil test P in the plow-layer deleted and the Leaf P Reduced Model also had the variate for the soil test P in the subsoil deleted.

The X variates in the complete model, the Curvilinear Model, included N fertilizer level (2, linear and squared variates), P fertilizer level (2), NP interaction, soil test P level in the plow-layer (2), soil test P level in the subsoil, method of fertilizer application, stand level, N x soil test P and P x soil test P interactions, Check percent N or percent N of the unfertilized treatment (2), Check percent P (2), Check percent N x Check percent P, N x Check percent N, P x Check percent N, N x Check percent P, P x Check percent P and Check percent N x soil test P interactions.

The R^2 of the Curvilinear, Linear, Soil Test P, Leaf P and Leaf P Reduced Models were 62.9, 57.3, 55.6, 59.4 and 59.4%, respectively. The addition of the five curvilinear (squared) variates, five leaf P variates and 5 or 6 soil test P variates gave highly significant reductions in the residual error. The addition of the variate for soil test P in the subsoil had no effect in the Leaf P Model but did have a significant effect in the Soil Test P Model. The change in percent P was estimated with 3.8% more precision by the Leaf P Models than by the Soil Test P Model although the highest precision occurred when both the leaf P and soil test P variates were included.

The significance levels of the partial regression coefficients of the variates were similar in the Curvilinear and Leaf P Models. However, the significance of several of the

variates differed between the Curvilinear and Soil Test P Models because of the significant correlation between the soil test P and leaf P variates, both of which indicated the P availability in the soil.

The changes in the dependent variate in these multiple regression equations on the increasing levels of the X variables were difficult to determine by visual inspection or by varying one variable and holding all others constant because of the correlation between variables and the presence of interactions. The first and second partial derivatives of the estimated change in percent P with respect to an X variable gave the slope and change in slope of the curve. However, if interactions occurred with the X variable, the slope also depended upon the levels of the associated variables. The slopes and changes in slope of the change in percent P on most of the X variables whose functions were curvilinear were similar to the behavior shown in the preliminary investigations. However, the changes in the change in percent P on the soil test P and Check percent N levels varied among the models. These effects appeared to be due to the correlation of both variables with the Check percent P variable. Most of the interaction variates had a significant effect on the change in percent P and their signs were the same as indicated in the preliminary investigations.

Three multiple regression equations were calculated for the regression of the percent P on selected X variates. The Curvilinear Model included 17 X variates, the Curvilinear Reduced Model had the two variates for the percent N deleted and the Linear Model had five variates for the squared terms in the curvilinear functions deleted. The X variates in the Curvilinear Model included N fertilizer level (2), P fertilizer level (2), NP interaction, soil test P level (2), soil test P in the subsoil, stand level, N x soil test P and P x soil test P interactions, percent N at the given levels of N and P fertilizer (2), Check percent N (2) and N x Check percent N and P x Check percent N interactions.

The regression of the percent P on the X variates was highly significant in all models; the R^2 of the Curvilinear, Curvilinear Reduced and Linear Models were 57.2, 54.8 and 55.2%, respectively. The addition of the two variates of the percent N variable and the five variates associated with the curvilinear functions gave highly significant reductions in the residual error. The significance of some of the variates varied considerably in the Curvilinear and Curvilinear Reduced Models. The slope and change in slope of the percent P on the N fertilizer and Check percent N levels also varied widely in the two models. The cause of these differences in the two models was the percent N variable which was highly correlated with the N fertilizer and Check percent N variables.

The change in yield was studied in detail and 10 regression equations were determined for the regression of the change in yield on selected X variates. The Curvilinear Complete Model included 23 X variates, the Linear Complete Model had five variates of the squared terms of the curvilinear functions deleted, the Soil Test P Model had the five leaf P variates deleted, the Leaf P-I Model had the five soil test P variates deleted and the Leaf P-II Model also had the variate for the soil test P in the subsoil deleted. In the corresponding Reduced Models, the Check yield variate was deleted from each since this variable may not be available in many cases.

The X variates included in the Curvilinear Complete Model for the change in yield dependent variate were the same as were included in the Curvilinear Model for the change in percent P except for the addition of the Check yield variate. The R^2 of the Curvilinear Complete, Linear Complete, Soil Test P, Leaf P-I and Leaf P-II Models were 70.5, 64.4, 60.8, 68.5 and 68.5%, respectively, and were 0.8, 1.6, 3.9, 0.6 and 0.6% higher, respectively, than their Reduced Models. The addition of the five variates associated with the curvilinear functions, the five leaf P variates, the five soil test P variates and the Check yield variate gave highly significant reductions in the residual error. The variate for the soil test P in the subsoil had no effect in the Leaf P Models.

The change in yield was estimated with considerably higher precision from the leaf P variates than from the soil test P variates, particularly in the absence of the Check yield variate. The R^2 of the Leaf P and Leaf P Reduced Models were 7.7 and 11.0% higher than the Soil Test P and Soil Test P Reduced Models, respectively.

The significance levels of most of the partial regression coefficients of the X variates were similar in all models, particularly among the Curvilinear and Leaf P Models. However, the significance of several of the variates associated with the soil test P and Check percent N variables varied widely among the Curvilinear and Soil Test P Models. The changes in the estimated yield response with increasing levels of the X variables were similar in all models for N and P fertilizer and Check percent P variables but were different for the soil test P and Check percent N variables because of their correlation with the Check percent P variable. The significance and direction of the interaction variates were generally similar to those determined in the preliminary investigations.

The small effects in the regression equations of the variates for the soil test P in the subsoil and method of P application were unexpected since their effects in the preliminary investigations appeared to be important. Further

research is needed on these variables in the different soil areas.

Economic analyses may be applied to the generalized yield response functions developed in this study to determine the economic optima of corn fertilization with N and P fertilizers at any N and P leaf composition level, soil test P level and stand level. The use of corn leaf composition data appears to give higher precision in the prediction of the yield response to fertilizer than the use of soil test data although the combination of the leaf analysis and soil test methods appears to give the highest precision. The yield response regression equations appear to be reasonable for a wide range of conditions although further research needs to determine if the precision is as high for the general population as for the experiments from which the regression equations were derived. The equations also need to be checked for predicting corn yield responses in the same field one or more years after the leaf samples are taken. The use of corn leaf composition also needs to be related to the fertilization of other crops in the rotation.

The regression of yield at any N and P fertilizer level on selected X variates was determined for four multiple regression models. The Curvilinear Complete Model included 17 X variates, the Linear Complete Model had six variates for the squared terms of the curvilinear functions deleted, the Curvi-

linear Leaf Model included seven variates for stand level and N and P leaf composition and the Linear Leaf Model had only four variates for stand, percent N, percent P and percent N x percent P interaction. The X variates in the Curvilinear Complete Model included N fertilizer level (2), P fertilizer level (2), NP interaction, soil test P level (2), soil test P in the subsoil, stand level (2), N x soil test P and P x soil test P interactions, percent N (2), percent P (2) and percent N x percent P interaction.

The R^2 of the Curvilinear Complete, Linear Complete, Curvilinear Leaf and Linear Leaf Models were 60.7, 56.0, 57.4 and 52.0%, respectively. The addition of the variates for the curvilinear functions and the variates in addition to the stand and leaf N and P variates gave highly significant reductions in the residual error.

Most of the variates in the Curvilinear and Linear Complete Models and all of the variates in the Curvilinear and Linear Leaf Models had a significant effect on the reduction of the residual error. The changes in the estimated yield with increasing levels of the X variables in the curvilinear functions were positive and decreasing, as expected, except for the soil test P variable. Its effect was different from expected because of the correlation with the leaf P variable.

Further research is needed to increase the precision in estimating the dependent variates. Additional variates which

may increase the precision or utility of these regression equations are: additional components of the two-factor interactions, three-factor interactions involving N and P fertilizer with leaf N and P and soil test P levels, soil test N and its interactions, fertilizer x stand level interactions, K fertilizer, soil test K, leaf K and their interactions with other variables and climatic variables.

The relationships of the estimated yield to the N and P concentrations in the corn leaf were determined from the regression equation of the Curvilinear Leaf Model in order to study the critical N and P percentages, nutrient balance and luxury consumption. The N and P percentages at the maximum yield were found to be 3.16 and 0.338%, respectively, and the maximum yield at these leaf levels and at the stand level at maximum yield was 113.5 bushels per acre. The relationships between the percent N and percent P in the corn leaf were also calculated and graphed for yields of 75, 90, 95 and 97% of the maximum yield.

The relationships between yield and N and P composition were analogous in most respects to the "contour maps" of the fertilizer-crop response relationship. The maximum yield occurred at a fixed ratio of percent N and percent P in the leaf but at yield levels below the maximum, the isoquants (lines connecting points of equal yield) showed that equal yields occurred with widely varying ratios of N and P in the corn

leaf. Hence, it appeared that N could substitute for P in the leaf at a decreasing rate, within limits, and maintain the same yield level. The ridge lines (lines connecting the points of zero rate of substitution on the isoquants) may have agronomic and economic significance. Corn whose leaf composition lies in the area outside of the two ridge lines may behave differently to fertilization than corn whose leaf composition lies within the ridge lines.

The concept that the critical nutrient percentage or level is a sharply-defined point or narrow range of values may be questioned as a result of this study. A broad range in the leaf composition values occurred from maximum yield to 97 or 95% of the maximum yield. The level of the leaf N for a given percentage yield also varied widely with the level of the percent P in the leaf because of the significant interaction between the two. The maximum yield for an increasing level of leaf N also varied with the level of the leaf P content. This concept of the relationship of yield to the leaf N and P levels also may be extended to other variables which have significant interactions with the leaf N and P levels. Hence, the critical level appears to include a wide range of values depending how it is defined and upon levels of other factors. Many of the present concepts on critical percentages appear to be only special cases in the general relationship

of yield and nutrient concentration to the critical percentage or level.

The balance between the N and P contents in the leaf appears to be critical only at yields near the maximum and becomes less critical as the yield decreases. Since the critical levels may vary widely, the concentration at which luxury consumption occurs also may vary widely.

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VIII. APPENDIX

Table 40. Location, year, soil type and previous cropping of all corn experiments

Expt. no.	Cooperator	County	Year	Soil type[a]	Previous cropping[b]
1.	Nissen	Benton	1948	Tama s.l.	SB-C-C-M-M
2.	Neibuhr	Benton	1948	Tama s.l.	C-M-O-C-C
3.	Davidson	Cedar	1948	Tama s.l.	C-M-M-O-C
4.	Fricke	Henry	1948	Taintor s.c.l.	C-M-O-C-C
5.	Rolfe	Cedar	1948	Muscatine s.l.	O(RC)-C-C-M
6.	Criswell	Jasper	1949	Tama s.l.	O(RC)-C-C
7.	Miller	Clayton	1950	Fayette s.l.	M-O-C-C-M
8.	Sorum	Winneshiek	1950	Downs s.l.	C-M-M-M-M
9.	Christiansen	Grundy	1950	Floyd s.l.	C-M-O-C-C
10.	Winter	Osceola	1950	Primghar s.l.	C-SB-C-M-O
11.	Fouche	Clarke	1950	Haig s.c.l.	C-C-M-O-C
12.	Bonnett	Van Buren	1950	Haig s.c.l.	M-M-O-C-C
13.	Retz	Delaware	1950	Clyde s.c.l.	C-M-O-C
14.	Kroese	O'Brien	1950	Galva s.l.	C-M-M-F-C
15.	Strand	Poweshiek	1950	Tama s.l.	C-B(SC)-C
16.	Tiedemann	Benton	1950	Tama s.l.	C-C-M-O-C
17.	Forsythe	Monroe	1950	Grundy s.l.	BG (30 yrs.)
18.	Roper	Greene	1951	Webster s.l.	O(RC)-C-C-C
19.	Smith	Greene	1951	Webster s.c.l.	M-M-O-C
20.	Purdie	Calhoun	1951	Nicollet s.l.	SC-O-C-SB
21.	Purdie	Calhoun	1951	Nicollet s.l.	SC-O-C-SB
22.	Fick	Lyon	1951	Galva s.l.	O-C-O-C
23.	Moeller	Lyon	1951	Moody s.l.	O(SC)-C-O(SC)
24.	Wittrock	Carroll	1951	Marshall s.l.	C-M-M-M
25.	Hanson	Monona	1951	Ida s.l.	O(SC)-C-C
26.	Hanson	Monona	1952	Ida s.l.	SC-O-C
27.	Selzer	Linn	1952	Carrington l.	M-M-O-C
28.	Coon	Greene	1952	Nicollet s.l.	C-C-O(SC)-C
29.	Hoskinson	Greene	1952	Clarion l.	C-SB-M-O
30.	Dehoney	Greene	1952	Clarion l.	SB-C-C

[a]Abbreviations: s.l. - silt loam, s.c.l. - silty clay loam, l. - loam, sa.l. - sandy loam, f.s.l. - fine sandy loam.

[b]Crop in the previous year is on the left of the series; from left to right, the preceding crops are shown. Abbreviations: C - corn, O - oats, SB - soybeans, M - meadow, F - flax, RC - red clover, SC - sweet clover, B - barley, A - alfalfa, W - wheat and BG - bluegrass pasture.

Table 40. (Continued)

Expt. no.	Cooperator	County	Year	Soil type[a]	Previous cropping[b]
31.	Sefcik	Pocahontas	1952	Nicollet s.l.	O-C-O-C-O
32.	Lyle	O'Brien	1952	Primghar s.l.	M-M-O-C
33.	Wittrock	O'Brien	1952	Marcus s.c.l.	SB-C-O-C
34.	Murchland	Crawford	1952	Ida s.l.	C-M-M-M
35.	Andringa	O'Brien	1952	Primghar s.l.	SB-C-SB
36.	Croat	Sioux	1952	Galva s.l.	F(RC)-C
37.	Buckley	Lyon	1952	Galva s.l.	C-SB-C-B(SC)
38.	Nagel	O'Brien	1952	Sac s.l.	M-O-C-O(SC)
39.	Elgersma	O'Brien	1952	Galva s.l.	M-O-C-O
40.	Skaar	O'Brien	1952	Galva s.l.	O-C-O(SC)-C
41.	Uthoff	Benton	1952	Tama s.l.	M-M-O-C
42.	Brockschink	Iowa	1952	Tama s.l.	M-M-O-C
43.	McCarty	O'Brien	1952	Primghar s.l.	M-O-SB-C
44.	Humes	Buchanan	1952	Carrington sa.l	M-M-O-C
45.	Ondler	Delaware	1952	Floyd s.l.	M-O-C
46.	Nipp	Plymouth	1952	Ida s.l.	O-C-O-C
47.	Neppl	Carroll	1952	Marshall s.l.	C-SC-O-C
48.	Elshuis	O'Brien	1952	Galva s.l.	O-C-C-C
49.	Riley	Lyon	1953	Moody s.l.	C-O-C
50.	Hughes	O'Brien	1953	Galva s.l.	SB-C-SB-C
51.	Van Dieren	Sioux	1953	Moody s.l.	O-C-O-C
52.	Wenzel	Lyon	1953	Moody s.l.	C-C-M-M
53.	Richards	Greene	1953	Webster s.c.l.	C-C-O
54.	Fechter	O'Brien	1953	Galva s.l.	SB-C-M-O
55.	Bayers	Guthrie	1953	Nicollet s.l.	SB-C-SB-C
56.	Cairns	Greene	1953	Clarion l.	SB-C-SB-C
57.	Anderson	O'Brien	1953	Marcus s.c.l.	M-F
58.	Mastbergen	O'Brien	1953	Marcus s.c.l.	SB-C-O-SB
59.	Cairns	Greene	1953	Clarion l.	SB-C-SB-C
60.	Anderson	O'Brien	1953	Marcus s.c.l.	M-F
61.	Mastbergen	O'Brien	1953	Marcus s.c.l.	SB-C-O-SB
62.	Dehoney	Greene	1953	Clarion l.	C-SB-C-C
63.	Cherry	Buchanan	1953	Carrington sa.l	C-O
64.	Bogge	Buchanan	1953	Carrington l.	C-M-O-C
65.	Schlumbohm	Fayette	1953	Carrington l.	M-M-O-C
66.	Yearous	Fayette	1953	Floyd s.l.	SB-C-M-O
67.	Satterlee	Buchanan	1953	Clyde s.c.l.	C-M-O-C
68.	County Farm	Allamakee	1953	Fayette s.l.	M-O-C-M
69.	Hansmeier	Allamakee	1953	Fayette s.l.	M-M-M-M
70.	Knittig	Calhoun	1953	Webster s.c.l.	SB-C-SB-C

Table 40. (Continued)

Expt. no.	Cooperator	County	Year	Soil type[a]	Previous cropping[b]
71.	Van Horn	Greene	1953	Webster s.c.l.	O(A)-C-C
72.	DePould	Greene	1953	Clarion l.	C-SB-C-O(SC)
73.	Cherry	Buchanan	1953	Carrington sa.l	C-O-C
74.	Drinkall	Des Moines	1953	Taintor s.c.l.	C-M-O-SB
75.	White	Page	1953	Sharpsburg s.l.	C-M-O-C
76.	Witt	Marshall	1953	Tama s.l.	C-O(SC)-C
77.	Smith	Fayette	1953	Carrington l.	SB-C-M
78.	Hinze	Fremont	1953	Sarpy f.s.l.	C-C-C
79.	Pierce	Fremont	1953	Haynie f.s.l.	C-Flooded-C
80.	Wright	Mills	1953	McPaul s.l.	C-Flooded-W
81.	Seedorf	Fayette	1954	Floyd s.l.	M-M-O-C
82.	Recker	Fayette	1954	Carrington l.	M-O-C
83.	Meisgeier	Delaware	1954	Carrington l.	M-O-C
84.	Manson	Delaware	1954	Floyd s.l.	C
85.	Haverkamp	Bremer	1954	Floyd s.l.	C-M-O-C
86.	Epley	Bremer	1954	O'Neill f.s.l.	C-M-M-O
87.	Schutte	Chickasaw	1954	Carrington l.	C-M-M-O
88.	Huber	Chickasaw	1954	Carrington l.	C-M-O-C
89.	Schemmel	Howard	1954	Carrington l.	C-C-M-O
90.	Anderson	O'Brien	1954	Marcus s.c.l.	O-C-C-SB
91.	Yeazel	Calhoun	1954	Webster s.c.l.	SB-C-M
92.	Taylor	Greene	1954	Nicollet s.l.	C-C-SB-C
93.	Vang	Winneshiek	1954	Downs s.l.	C-M-O
94.	Snitker	Allamakee	1954	Fayette s.l.	M-O-C
95.	Ankeny Farm	Polk	1954	Nicollet s.l.	SB-C
96.	Holsclaw	Fremont	1954	McPaul s.l.	C-Flooded
97.	Parkison	Fremont	1954	Wabash s.c.l.	C-Flooded
98.	Nelson	Fayette	1955	Fayette s.l.	M-O-C-M
99.	Frieden	Fayette	1955	Fayette s.l.	M-M-O-C
100.	Behnken	Clayton	1955	Fayette s.l.	M-M-M-O-C
101.	Drees	Delaware	1955	Carrington l.	M-M-O-C
102.	Sandman	Delaware	1955	Floyd s.l.	M-O-C-C
103.	Wacker	Delaware	1955	Carrington l.	C-M-O
104.	Beda	Mills	1955	Bottomland	C-W
105.	Cairns	Greene	1956	Clarion l.	SB-C-SB-C
106.	Birney	Washington	1956	Mahaska s.l.	C-M-M-O
107.	Frisk	Henry	1956	Mahaska s.l.	C-C-M
108.	Moore	Lee	1956	Belinda s.l.	C-C-Idle
109.	Smith	Allamakee	1956	Fayette s.l.	M-O-C-M
110.	Larson	Winneshiek	1956	Downs s.l.	M-O-C-M

Table 40. (Continued)

Expt. no.	Cooperator	County	Year	Soil type[a]	Previous cropping[b]
111.	Baade	Clayton	1956	Fayette s.l.	M-O-C-M
112.	Yearous	Clayton	1956	Fayette s.l.	M-O-C-M
113.	Rausch	Dubuque	1956	Fayette s.l.	M-O-C-M
114.	Singsank	Dubuque	1956	Fayette s.l.	M-O-C-M
115.	Steege	Chickasaw	1956	Carrington l.	M-O-SB-C
116.	Exptl. Farm	Howard	1956	Floyd s.l.	C-SB
117.	Blok	O'Brien	1956	Galva s.l.	SB-C-M-O
118.	Neese	Greene	1956	Nicollet s.l.	SB-C-SB-C
119.	Dibble	Buchanan	1956	Carrington l.	C-M-O-C-C
120.	Bailey	Henry	1956	Weller s.l.	C-M-W

Table 41. Type of experiment, soil test results and K level of NP treatments of all experiments

Expt. no.	Type of experiment[a]	Soil test results					K level of NP[d] tmts.
		pH	N[b]	P[b]	K[b]	Psub.[c]	
1.	2x2x2 NPK	5.1	--	11.0	400	10.0[e]	0,60
2.	2x2x2 NPK	5.4	--	4.0	210	10.0[e]	0,60
3.	2x2x2 NPK	5.8	--	18.0	400	10.0[e]	0,60
4.	2x2x2 NPK	5.5	--	8.0	170	7.0[e]	0,60
5.	3x3 Fert. x St.	5.3	--	7.0	190	10.0[e]	--
6.	2x2x2 NPK-R,St.	5.5	66	4.3	220	10.0[e]	0,60
7.	2x2x2 NPK-R	5.9	74	6.0	170	30.0[e]	60
8.	2x2x2 NPK	6.5	42	2.5	170	7.0	60
9.	2x2x2 NPK	5.5	80	5.5	165	1.0[e]	0,60
10.	2x2x2 NPK-R	5.8	116	3.0	220	1.0	0,40

[a]Most experiments were factorials with variables and levels as listed. Individual treatments with levels of N and P are given in Tables 42 and 43. R = split plots without and with hill or row fertilizer. N = split plots without and with additional N fertilizer. Meth. = split plots with two different methods of application. St. = stand level variables. I = experiments with different levels of nutrients but with an incomplete number of treatments for a complete factorial.

[b]Soil test results are given in pounds per acre in the surface plow-layer as determined by the Iowa State College Soil Testing Laboratory.

[c]P subsoil tests are given in pounds per acre 6 2/3 inches, averaged over samples taken from 1 to 2 and 2 to 3 feet depths.

[d]Where K fertilizer was a variable, N and P fertilizer effects on yields and composition were either averaged over two or more K levels or determined at one K level, as listed. No values show that K fertilizer was not a variable. If the K level is preceded by B, all treatments had a basic application of K level indicated. K levels refer to pounds per acre of K_2O.

[e]Indicates that samples were not taken from the experimental site but values were estimated from soil type means.

Table 41. (Continued)

Expt. no.	Type of experiment[a]	Soil test results pH	N[b]	P[b]	K[b]	Psub.[c]	K level of NP[d] tmts.
11.	2x2x2 NPK	5.5	44	5.6	200	7.0[e]	0,60
12.	2x2x2 NPK-R	6.0	56	5.2	130	7.0[e]	60
13.	2x2x3 NPK	6.3	--	6.5	115	1.2[e]	80
14.	2x2 NP	6.0	188	3.8	260	1.1	--
15.	2x2 NP	6.5	60	11.2	350	10.0[e]	--
16.	3x3 NP	5.4	82	2.5	235	5.4	--
17.	3x3 NP	5.3	--	2.0	220	3.0[e]	--
18.	2x2x2 NPK-R	7.7	166	3.7	200	0.8[e]	0,60
19.	2x3x2 NPK-R	7.1	120	5.1	256	0.8[e]	0,60
20.	3x2 PK-R	6.6	--	1.0	210	0.8[e]	0,40
21.	3x2 PK-R	6.6	--	1.0	210	0.8[e]	0,40
22.	3x3 NP-R	6.0	114	7.0	400	0.8	--
23.	3x3 NP-R	6.2	136	5.0	372	1.5	--
24.	3x3 NP-R	6.1	42	3.5	332	5.0[e]	--
25.	3x3 NP-R	7.8	96	1.0	138	0.5[e]	--
26.	9x9 NP	7.9	20	0.5	296	0.5[e]	--
27.	NPK Rates-N	6.1	96	3.0	126	1.5[e]	0,60,120
28.	NPK Rates-N	6.4	108	4.2	208	0.8[e]	0,60,120
29.	NPK Rates-N	5.7	76	5.0	152	0.8[e]	0,60,120
30.	NPK Rates-N	5.7	106	5.8	182	0.8[e]	0,60,120
31.	2x2x2 NPK-R	6.6	90	7.3	168	0.8[e]	0,60
32.	NP Rates-N	5.8	174	4.2	300	1.0[e]	--
33.	NP Rates-N	6.6	144	6.7	328	0.8[e]	--
34.	NP Rates-N	7.8	78	3.0	220	0.5[e]	--
35.	3x3 NP-R	6.4	136	4.0	238	1.0[e]	--
36.	3x3 NP-R	6.2	140	4.5	400	1.0[e]	--
37.	3x3 NP-R	5.7	136	8.5	350	1.0[e]	--
38.	2x3 NP-Meth.	5.9	136	2.2	300	0.5	--
39.	2x3 NP-Meth.	5.8	194	4.0	320	1.3	--
40.	3x3 NP-Meth.	6.3	158	7.0	302	0.5	--
41.	3x3 NP-Meth.	5.6	136	3.2	224	4.4	--
42.	2x3 NP-Meth.	5.6	100	1.8	228	2.5	B-40
43.	P Rates-Meth.	6.8	200	1.7	400	0.5	--
44.	3x3 PK-Meth.	6.8	--	1.5	54	1.0	80
45.	3x3 PK-Meth.	5.5	--	1.3	108	1.0[e]	80
46.	NP Rates	7.9	50	2.5	216	0.5[e]	--
47.	4x2 NP	6.1	120	6.5	400	5.0[e]	--
48.	4x2 NP	6.3	44	4.7	230	1.0[e]	--
49.	2x2 NP	6.2	--	10.0	400	1.5[e]	--
50.	4x3 NP-I	6.6	--	3.7	316	1.0[e]	--

Table 41. (Continued)

Expt. no.	Type of experiment[a]	Soil test results pH	N[b]	P[b]	K[b]	Psub.[c]	K level of NP tmts.[d]
51.	4x3 NP-I	6.4	--	3.0	356	1.5[e]	--
52.	4x3 NP-I	6.1	--	6.0	350	1.5[e]	--
53.	2x2 NP	6.7	--	5.0	226	0.8[e]	--
54.	2x2 NP-Meth.	5.8	--	3.5	270	1.0[e]	--
55.	3x2 NP-Meth.	6.8	--	2.0	140	0.8[e]	B-60
56.	3x2 NP-Meth.	5.8	--	4.0	176	0.8[e]	B-60
57.	3x2 NP-Meth.	7.1	--	1.0	296	0.5[e]	--
58.	3x2 NP-Meth.	6.6	--	1.5	272	0.8[e]	B-60
59.	P Rates-Meth.	5.8	--	3.3	178	0.8[e]	B-60
60.	P Rates-Meth.	7.1	--	1.0	316	0.5[e]	--
61.	P Rates-Meth.	6.6	--	2.2	289	0.8[e]	B-60
62.	P Rates	5.8	--	3.5	188	0.8[e]	B-60
63.	2x2x3 NPK-R	5.7	--	7.0	120	1.5	60,120
64.	2x2x3 NPK-R	6.1	--	6.5	142	1.8	60,120
65.	2x2x3 NPK-R	5.4	--	1.2	95	0.8	0,60,120
66.	2x2x3 NPK-R	6.2	--	3.2	120	1.0	60,120
67.	2x2x3 NPK-R	6.3	--	7.0	95	1.2	60,120
68.	2x2x3 NPK-R	6.7	--	6.0	140	26.0	0,60,120
69.	2x2x3 NPK	6.3	--	3.0	80	30.0[e]	0,60,120
70.	4x3x3 NPK-I	6.8	--	4.7	174	0.8[e]	0
71.	4x3x3 NPK-I	7.5	--	4.7	175	0.8[e]	0
72.	4x3x3 NPK-I	6.3	--	1.5	150	0.8[e]	0
73.	4x3x3 NPK-I	5.7	--	7.0	106	1.5	0
74.	4x3x3 NPK-I	6.9	--	8.0	256	7.0[e]	0
75.	4x3x3 NPK-I	5.8	--	4.0	400	5.0[e]	0,60,120
76.	5x4x3 NPK	6.1	--	5.5	282	8.6	0,40,80
77.	5x4x3 NPK	6.0	--	7.2	110	2.0[e]	40,80
78.	3x3x3 NPK	6.7	--	2.0	400	0.8	0,40
79.	3x3x3 NPK	7.4	--	10.0	400	0.5	0
80.	3x3x3 NPK	6.4	82	15.0	400	0.8[e]	0
81.	2x2x3 NPK-R	6.3	62	1.0	60	0.5	30,60
82.	2x2x3 NPK-R	5.9	120	2.2	80	0.8	30,60
83.	2x2x3 NPK-R	5.7	90	6.0	98	2.2	0,30,60
84.	2x2x3 NPK-R	5.7	93	1.2	116	0.5	0
85.	2x2x3 NPK-R	5.9	126	4.7	150	0.8	0
86.	2x2x3 NPK-R	6.5	104	7.5	120	3.2	0,30,60
87.	2x2x3 NPK-R	5.4	90	4.0	114	0.8	0
88.	2x2x3 NPK-R	7.0	87	4.2	96	0.5	0,30,60
89.	2x2x3 NPK-R	5.9	85	8.0	152	3.5	30,60
90.	2x2 NP	6.8	93	4.2	297	0.5	--

Table 41. (Continued)

Expt. no.	Type of experiment[a]	Soil test results					K level of NP tmts.[d]
		pH	N[b]	P[b]	K[b]	Psub.[c]	
91.	P Rates	6.6	--	5.3	208	0.8[e]	B-60
92.	2x2 NP	6.2	128	10.5	204	0.8[e]	--
93.	2x2x3 NPK	5.6	--	3.5	108	9.5	0,15,30
94.	2x2x3 NPK	6.2	--	1.5	104	18.5	15,30
95.	5x4x4 NPK	6.2	78	6.1	172	0.8[e]	0,40,80
96.	4x3x2 NPK-St.	8.1	81	3.5	400	0.8[e]	0,60
97.	4x3x2 NPK-St.	8.2	76	1.2	400	0.8[e]	0,60
98.	2x2x3 NPK-R	6.4	126	2.0	180	30.0[e]	0
99.	2x2x3 NPK-R	6.6	139	2.4	120	30.0[e]	0,30,60
100.	2x2x3 NPK	5.9	140	1.2	124	30.0[e]	0,30,60
101.	3x3 PK-Meth.	6.0	28	3.3	116	1.2	0,30,60
102.	3x3 PK-Meth.	6.5	79	6.0	151	1.2	0,30,60
103.	5x4x4 NPK	6.1	172	2.7	153	0.8[e]	0,40,80
104.	9x9 NP	7.9	190	2.7	400	0.8[e]	--
105.	2x4 NP	5.8	97	2.1	200	0.8[e]	B-60
106.	3x3x2 NPK-R	5.2	93	4.5	162	5.0	0,40
107.	3x3x2 NPK-R	5.5	134	3.5	194	1.8	0,40
108.	3x3x2 NPK-R	6.1	80	3.0	124	2.8	0,40
109.	3x2x2 NPK-R	6.4	90	4.8	184	30.0[e]	0,40
110.	3x2x2 NPK-R	6.4	87	1.8	158	9.0[e]	0,40
111.	3x2x2 NPK-R	6.7	99	2.2	138	30.0[e]	0,40
112.	3x2x2 NPK-R	6.7	85	2.7	94	30.0[e]	0
113.	3x2x2 NPK-R	7.2	72	6.5	144	30.0[e]	0,40
114.	3x2x2 NPK-R	6.5	114	4.8	191	30.0[e]	0,40
115.	3x3 PK	5.7	68	1.1	84	0.8	60
116.	3x3 PK	5.9	109	3.1	135	1.0[e]	30,60
117.	3x3 NP	6.2	141	5.8	400	1.0[e]	B-40
118.	3x3 NP-Meth.	6.2	103	1.3	189	0.8[e]	B-60
119.	9x9x9 NPK-I	5.8	--	2.5	167	1.5[e]	0,90;60
120.	9x9x9 NPK-I	5.5	76	1.5	100	4.9	90

Table 42. Method of P application, stand level, fertilizer treatment, yield and N and P leaf contents of the individual treatments of the experiments used in the multiple regression analyses

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
1-1	BPU	13.9	0	0	86.8	--	1.87	.202	--
2			60	0	100.3	13.5	2.22	.215	.013
3			0	60	87.2	0.4	1.74	.185	-.017
4			60	60	101.4	14.6	2.24	.230	.028
2-1	BPU	10.3	0	0	85.4	--	2.39	.210	--
2			60	0	85.5	0.1	2.64	.219	.009
3			0	60	92.2	6.8	2.28	.232	.022
4			60	60	97.0	11.6	2.57	.250	.040
3-1	BPU	11.8	0	0	106.1	--	2.36	.265	--
2			60	0	115.2	9.1	2.52	.272	.007
3			0	60	109.8	3.7	2.31	.269	.004
4			60	60	111.0	4.9	2.46	.297	.032
4-1	BPU	16.8	0	0	106.4	--	2.38	.256	--
2			60	0	110.8	4.4	2.64	.264	.008
3			0	60	112.4	6.0	2.25	.262	.006
4			60	60	122.1	15.7	2.60	.287	.031

[a]Mean stand level in thousands of stalks per acre are for all treatments if listed once per experiment; if fertilizer treatment had a significant effect on stand levels, stands are listed for each treatment.

[b]First figure refers to the pounds of N per acre; second figure is the pounds of P_2O_5 per acre. All treatments are without hill or row fertilizer.

[c]Yields in bushels per acre and N and P percentages for each experiment are at the K level or levels given in Table 41. Change in yield or percent P (Δyield or Δ%P) is based on the unfertilized treatment (0-0).

[d]First figure refers to experiment number and is listed once; second figure refers to treatment number.

[e]Method of P application: BPU = broadcast and plowed under, BDI = broadcast and disked in, HL = hard-ground listed. Method(s) listed once per experiment.

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
5-1	BPU	11.5	0	0	104.4	--	2.42	.321	--
2			40	0	109.2	4.8	2.64	.321	.000
3			40	40	109.4	5.0	2.59	.352	.031
4		15.6	0	0	116.0	--	2.15	.290	--
5			40	0	120.5	4.5	2.64	.320	.030
6			40	40	120.7	4.7	2.31	.328	.038
7		19.2	0	0	114.5	--	2.12	.282	--
8			40	0	116.7	2.2	2.29	.273	-.009
9			40	40	119.2	4.7	2.17	.317	.035
6-1	BPU	10.2	0	0	66.6	--	1.94	.200	--
2			60	0	90.4	23.8	2.53	.244	.044
3			0	60	69.4	2.8	1.80	.194	-.006
4			60	60	91.8	25.2	2.65	.272	.072
1		14.1	0	0	56.5	--	1.60	.160	--
2			60	0	89.8	33.3	2.38	.226	.066
3			0	60	55.6	- 0.9	1.62	.186	.026
4			60	60	94.1	37.6	2.40	.249	.089
7-1	BPU	9.1	0	0	29.3	--	2.85	.256	--
2			60	0	36.3	7.0	2.93	.264	.008
3			0	60	39.0	9.7	2.72	.274	.018
4			60	60	49.3	20.0	2.88	.299	.043
8-1	BPU	16.3	0	0	47.1	--	1.91	.198	--
2			60	0	65.2	18.1	2.61	.218	.020
3			0	60	38.5	- 8.6	1.60	.203	.005
4			60	60	88.2	41.1	2.50	.269	.071
9-1	BPU	10.6	0	0	49.0	--	1.95	.192	--
2			60	0	51.4	2.4	2.32	.202	.010
3			0	60	51.0	2.0	1.88	.193	.001
4			60	60	56.5	7.5	2.33	.226	.034
10-1	BPU	11.5	0	0	39.5	--	2.50	.180	--
2			40	0	42.8	3.3	2.72	.179	-.001
3			0	40	53.8	14.3	2.32	.202	.022
4			40	40	64.8	25.3	2.46	.214	.034
11-1	BPU	10.3	0	0	47.1	--	2.34	.240	--
2		10.9	60	0	65.2	18.1	3.06	.276	.036
3		10.3	0	60	46.2	- 0.9	2.13	.241	.001
4		10.9	60	60	67.8	20.7	2.85	.274	.034

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
12-1	BPU	10.7	0	0	55.2	--	2.28	.269	--
2			60	0	73.7	18.5	2.57	.298	.029
3			0	60	59.9	4.7	2.22	.310	.041
4			60	60	76.0	20.8	2.54	.305	.036
14-1	BPU	14.1	0	0	73.2	--	2.95	.251	--
2			40	0	75.9	2.7	3.05	.267	.016
3			0	40	81.4	8.2	2.99	.283	.032
4			40	40	82.1	8.9	3.04	.285	.034
15-1	BPU	10.3	0	0	67.9	--	2.92	.291	--
2			60	0	69.7	1.8	2.98	.295	.004
3			0	60	70.2	2.3	2.84	.298	.007
4			60	60	70.5	2.6	2.96	.301	.010
16-1	BPU	14.5	0	0	63.7	--	2.11	.193	--
2			40	0	64.3	0.6	2.35	.198	.005
3			80	0	60.7	- 3.0	2.41	.211	.018
4			0	40	63.6	- 0.1	1.95	.192	-.001
5			40	40	72.6	8.9	2.25	.209	.016
6			80	40	79.8	16.1	2.51	.231	.038
7			0	80	68.3	4.6	2.14	.206	.013
8			40	80	71.9	8.2	2.30	.216	.023
9			80	80	79.4	15.7	2.46	.238	.045
17-1	BPU	8.8	0	0	66.9	--	2.54	.256	--
2			40	0	66.9	0.0	2.56	.232	-.024
3			80	0	76.2	9.3	2.76	.240	-.016
4			0	40	63.1	- 3.8	2.48	.286	.030
5			40	40	72.1	5.2	2.52	.264	.008
6			80	40	88.7	21.8	2.68	.286	.030
7			0	80	76.7	9.8	2.38	.283	.027
8			40	80	72.7	5.8	2.48	.278	.022
9			80	80	89.2	22.3	2.62	.283	.027
18-1	BDI	14.6	0	0	57.4	--	1.96	.217	--
2			60	0	78.0	20.6	2.56	.224	.007
3			0	60	58.2	0.8	1.91	.232	.015
4			60	60	91.0	33.6	2.54	.279	.062
19-1	BDI	12.1	0	0	80.7	--	2.60	.279	--
2			60	0	90.1	9.4	2.70	.288	.009
3			0	60	86.1	5.4	2.42	.316	.037
4			0	120	82.2	1.5	2.38	.322	.043

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
19-5	BDI	12.1	60	60	96.7	16.0	2.70	.302	.023
6			60	120	91.4	10.7	2.74	.338	.059
20-1	BDI	13.1	0	0	66.8	--	2.42	.230	--
2			0	40	81.3	14.5	2.35	.260	.030
3			0	80	81.5	14.7	2.31	.271	.041
21-1	BPU	13.4	0	0	61.5	--	2.48	.255	--
2			0	40	67.1	5.6	2.18	.280	.025
3			0	80	68.6	7.1	2.12	.291	.036
23-1	BPU	11.4	0	0	65.4	--	2.60	.270	--
2			40	0	64.0	- 1.4	2.77	.260	-.010
3			80	0	68.7	3.3	2.87	.270	.000
4			0	40	69.5	4.1	2.60	.292	.022
5			40	40	71.6	6.2	2.80	.298	.028
6			80	40	76.6	11.2	2.98	.292	.022
7			0	80	66.9	1.5	2.70	.285	.015
8			40	80	73.8	8.4	2.82	.320	.050
9			80	80	76.2	10.8	2.84	.308	.038
24-1	BPU	13.6	0	0	76.0	--	2.74	.270	--
2			40	0	82.0	6.0	2.95	.273	.003
3			80	0	87.0	11.0	2.99	.268	-.002
4			0	40	80.5	4.5	2.78	.288	.018
5			40	40	88.7	12.7	2.86	.288	.018
6			80	40	88.5	12.5	2.99	.305	.035
7			0	80	80.0	4.0	2.60	.292	.022
8			40	80	88.7	12.7	2.88	.302	.032
9			80	80	87.3	11.3	2.99	.320	.050
25-1	BPU	10.3	0	0	8.1	--	2.15	.123	--
2			40	0	10.2	2.1	2.43	.117	-.006
3			80	0	10.5	2.4	2.41	.110	-.013
4			0	40	18.7	10.6	1.80	.188	.065
5			40	40	34.1	26.0	2.23	.173	.050
6			80	40	34.8	26.7	2.59	.183	.060
7			0	80	21.8	13.7	1.73	.197	.074
8			40	80	37.9	29.8	2.13	.205	.082
9			80	80	52.9	44.8	2.59	.245	.122
26-1	BPU	18.1	0	0	15.4	--	1.88	.104	--
2			80	0	17.6	2.2	2.23	.098	-.006
3			160	0	10.8	- 4.6	1.93	.093	-.011

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
26-4	BPU	18.1	0	80	26.4	11.0	1.20	.132	.028
5			80	80	107.4	92.0	2.46	.257	.153
6			160	80	94.2	78.8	2.38	.210	.106
7			0	160	23.0	7.6	1.08	.137	.033
8			80	160	105.4	90.0	2.44	.258	.154
9			160	160	123.0	107.6	2.62	.281	.177
27-1	BPU	13.0	0	0	105.2	--	2.72	.230	--
2			60	0	102.9	- 2.3	2.62	.230	.000
3			60	60	129.0	23.8	2.66	.345	.115
4			120	60	125.9	20.7	2.65	.345	.115
5			120	120	133.4	28.2	2.75	.370	.140
6			180	120	129.2	24.0	2.67	.360	.130
28-1	BPU	13.3	0	0	60.7	--	2.38	.234	--
2			60	0	79.7	19.0	2.80	.252	.018
3			60	60	94.9	34.2	2.44	.259	.025
4			120	60	103.5	42.8	2.68	.278	.044
5			120	120	113.5	52.8	2.67	.299	.065
6			180	120	117.3	56.6	2.84	.300	.066
29-1	BPU	13.5	0	0	70.2	--	2.75	.222	--
2			60	0	77.0	6.8	2.98	.212	-.010
3			60	60	99.2	29.0	2.81	.270	.048
4			120	60	113.2	43.0	3.02	.293	.071
5			120	120	115.0	44.8	2.96	.308	.086
6			180	120	114.5	44.3	3.06	.301	.079
30-1	BPU	12.0	0	0	75.2	--	2.65	.227	--
2			60	0	78.7	3.5	2.92	.219	-.008
3			60	60	103.1	27.9	2.71	.248	.021
4			120	60	111.8	36.6	2.87	.267	.040
5			120	120	114.5	39.3	2.88	.269	.042
6			180	120	115.6	40.4	2.95	.269	.042
31-1	BDI	13.3	0	0	59.3	--	1.70	.182	--
2			60	0	98.5	39.2	2.45	.226	.044
3			0	60	51.4	- 7.9	1.52	.176	-.006
4			60	60	95.1	35.8	2.32	.232	.050
5			120	120	110.2	50.9	2.64	.271	.089
33-1	BPU	14.7	0	0	81.6	--	2.77	.234	--
2			60	0	90.2	8.6	3.01	.248	.014
3			60	60	111.7	30.1	2.81	.262	.028

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
33-4	BPU	14.7	120	60	110.9	29.3	3.14	.264	.030
5			120	120	118.0	36.4	3.20	.281	.047
6			180	120	124.0	42.4	3.14	.272	.038
34-1	BPU	9.5	0	0	73.1	--	3.04	.228	--
2		9.5	60	0	65.9	- 7.2	3.08	.205	-.023
3		10.7	60	60	104.2	31.1	3.10	.296	.068
4		10.7	120	60	101.8	28.7	3.22	.278	.050
5		11.1	120	120	118.3	45.2	3.12	.340	.112
6		11.1	180	120	113.2	40.1	3.26	.346	.118
35-1	BPU	11.5	0	0	74.1	--	3.03	.244	--
2			40	0	80.1	6.0	2.90	.226	-.018
3			80	0	75.3	1.2	3.12	.246	.002
4			0	40	90.8	16.7	3.03	.256	.012
5			40	40	90.2	16.1	3.13	.264	.020
6			80	40	90.3	16.2	3.11	.292	.048
7			0	80	91.2	17.1	3.00	.264	.020
8			40	80	95.3	21.2	3.06	.271	.027
9			80	80	98.2	24.1	3.11	.287	.043
36-1	BPU	12.2	0	0	70.9	--	3.09	.222	--
2			40	0	80.4	9.5	3.06	.233	.011
3			80	0	75.3	4.4	3.12	.222	.000
4			0	40	81.8	10.9	3.08	.248	.026
5			40	40	93.0	22.1	3.00	.238	.016
6			80	40	91.0	20.1	3.14	.252	.030
7			0	80	86.5	15.6	2.83	.246	.024
8			40	80	96.1	25.2	3.10	.262	.040
9			80	80	99.2	28.3	3.22	.260	.038
37-1	BPU	9.8	0	0	58.6	--	2.55	.235	--
2			40	0	70.5	11.9	3.02	.233	-.002
3			80	0	73.6	15.0	3.03	.245	.010
4			0	40	58.0	- 0.6	2.46	.225	-.010
5			40	40	67.7	9.1	2.75	.232	-.003
6			80	40	78.1	19.5	3.02	.262	.027
7			0	80	62.6	4.0	2.44	.256	.021
8			40	80	75.0	16.4	2.82	.260	.025
9			80	80	76.2	17.6	2.98	.278	.043
38-1	BPU	14.0	0	0	84.1	--	2.42	.198	--
2			40	0	96.3	12.2	2.42	.233	.035
3			0	40	105.6	21.5	2.38	.227	.029

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
38-4	BPU	14.0	0	80	103.0	18.9	2.20	.251	.053
5			40	40	112.0	27.9	2.55	.254	.056
6			40	80	110.3	26.2	2.39	.252	.054
2	BDI		40	0	96.3	12.2	2.71	.205	.007
3			0	40	98.0	13.9	2.14	.219	.021
4			0	80	99.0	14.9	2.30	.260	.062
5			40	40	108.4	24.3	2.45	.241	.043
6			40	80	111.4	27.3	2.62	.263	.065
39-1	BPU	12.7	0	0	91.3	--	2.82	.224	--
2			40	0	101.8	10.5	2.88	.230	.006
3			0	40	109.1	17.8	2.81	.262	.038
4			0	80	111.5	20.2	2.90	.277	.053
5			40	40	113.0	21.7	2.97	.257	.033
6			40	80	112.7	21.4	2.92	.281	.057
2	BDI		40	0	99.0	7.7	2.88	.228	.004
3			0	40	106.1	14.8	2.83	.247	.023
4			0	80	107.9	16.6	2.79	.241	.017
5			40	40	109.3	18.0	2.87	.248	.024
6			40	80	106.6	15.3	2.94	.253	.029
40-1	BPU	11.2	0	0	78.0	--	2.20	.225	--
2			40	0	86.4	8.4	2.41	.241	.016
3			80	0	85.2	7.2	2.70	.255	.030
4			0	40	81.9	3.9	2.31	.232	.007
5			40	40	93.0	15.0	2.57	.241	.016
6			80	40	96.6	18.6	2.68	.272	.047
7			0	80	73.2	- 4.8	2.27	.242	.017
8			40	80	88.7	10.7	2.71	.252	.027
9			80	80	94.4	16.4	2.71	.271	.046
2	BDI		40	0	86.9	8.9	2.74	.234	.009
3			80	0	88.1	10.1	2.82	.253	.028
4			0	40	76.5	- 1.5	2.14	.230	.005
5			40	40	91.0	13.0	2.70	.238	.013
6			80	40	94.1	16.1	2.79	.265	.040
7			0	80	67.8	-10.2	2.31	.216	-.009
8			40	80	89.6	11.6	2.58	.259	.034
9			80	80	93.3	15.3	2.73	.273	.048
42-1	BPU	12.8	0	0	86.6	--	2.59	.219	--
2			40	0	86.3	- 0.3	2.70	.196	-.023
3			0	40	102.7	16.1	2.44	.246	.027
4			0	80	110.0	23.4	2.66	.277	.058
5			40	40	114.0	27.4	2.92	.254	.035

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Trt.[b] N	Trt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
42-6	BPU	12.8	40	80	120.0	33.4	2.79	.266	.047
2	BDI		40	0	89.3	2.7	2.71	.211	-.008
3			0	40	100.0	13.4	2.66	.229	.010
4			0	80	108.0	21.4	2.56	.258	.039
5			40	40	105.0	18.4	2.93	.253	.034
6			40	80	119.0	32.4	2.84	.252	.033
43-1	BPU	13.6	0	0	111.5	--	2.55	.221	--
2			0	40	127.2	15.7	2.54	.264	.043
3			0	80	126.2	14.7	2.53	.277	.056
2	BDI		0	40	122.6	11.1	2.67	.265	.044
3			0	80	127.9	16.4	2.42	.264	.043
45-1	BPU	13.8	0	0	91.0	--	2.99	.225	--
2			0	40	111.7	20.7	2.85	.260	.035
3			0	80	114.7	23.7	3.06	.283	.058
1	BDI		0	0	91.3	--	2.99	.215	--
2			0	40	104.7	13.4	2.85	.248	.033
3			0	80	102.3	11.0	3.06	.260	.045
46-1	BPU	10.2	0	0	14.0	--	1.49	.114	--
2			40	40	43.0	29.0	1.54	.140	.026
3			80	80	61.7	47.7	2.08	.186	.072
4			160	160	85.7	71.7	2.38	.236	.122
47-1	BPU	14.1	0	0	90.3	--	2.88	.245	--
2			60	0	106.6	16.3	3.13	.244	-.001
3			120	0	110.2	19.9	3.25	.243	-.002
4			180	0	106.6	16.3	3.33	.241	-.004
5			0	120	106.3	16.0	2.73	.250	.005
6			60	120	113.4	23.1	3.14	.263	.018
7			120	120	114.3	24.0	3.20	.274	.029
8			180	120	112.2	21.9	3.07	.280	.035
49-1	BPU	13.5	0	0	42.4	--	1.78	.210	--
2			60	0	64.9	22.5	2.58	.270	.060
3			0	60	54.3	11.9	1.72	.240	.030
4			60	60	68.1	25.7	2.42	.278	.068
5			120	120	71.6	29.2	2.44	.280	.070
50-1	BPU	11.9	0	0	70.5	--	2.42	.220	--
2			60	0	74.5	4.0	2.68	.205	-.015
3			120	0	74.0	3.5	2.76	.206	-.014
4			180	0	72.0	1.5	2.64	.191	-.029

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[e] %N	Leaf content[e] %P	Leaf content[e] Δ%P
50-5	BPU	11.9	0	60	63.5	- 7.0	2.17	.230	.010
6			60	60	87.5	17.0	2.50	.248	.028
7			120	60	93.5	23.0	2.79	.260	.040
8			180	60	98.0	27.5	2.78	.255	.035
9			120	120	104.0	33.5	2.76	.282	.062
10			180	120	101.5	31.0	2.90	.280	.060
51-1	BPU	11.6	0	0	65.7	--	2.17	.250	--
2			60	0	81.9	16.2	2.64	.265	.015
3			120	0	92.7	27.0	2.91	.272	.022
4			180	0	91.0	25.3	2.74	.280	.030
5			0	60	72.5	6.8	2.35	.302	.052
6			60	60	89.7	24.0	2.70	.302	.052
7			120	60	93.0	27.3	2.74	.310	.060
8			180	60	100.3	34.6	2.67	.320	.070
9			120	120	100.5	34.8	2.52	.338	.088
10			180	120	101.5	35.8	2.61	.332	.082
53-1	BPU	11.9	0	0	37.6	--	1.78	.264	--
2			180	0	65.5	27.9	2.61	.241	-.023
3			0	120	36.1	- 1.5	1.49	.295	.031
4			180	120	82.9	45.3	2.44	.320	.056
54-1	BPU	12.3	0	0	88.0	--	2.62	.229	--
2			60	0	89.1	1.1	2.69	.226	-.003
3			0	60	98.2	10.2	2.74	.270	.041
4			60	60	101.6	13.6	2.74	.275	.046
2	BDI		60	0	89.3	1.3	2.73	.222	-.007
3			0	60	96.6	8.6	2.64	.250	.021
4			60	60	94.5	6.5	2.76	.246	.017
55-1	BPU	12.3	0	0	66.8	--	2.16	.205	--
2			40	0	70.9	4.1	2.20	.212	.007
3			80	0	68.6	1.8	2.51	.221	.016
4			0	80	78.2	11.4	2.08	.263	.058
5			40	80	87.6	20.8	2.32	.278	.073
6			80	80	94.5	27.7	2.54	.303	.098
2	BDI		40	0	69.2	2.4	2.30	.205	.000
3			80	0	68.5	1.7	2.37	.204	-.001
4			0	80	74.0	7.2	1.99	.227	.022
5			40	80	84.2	17.4	2.31	.248	.043
6			80	80	93.7	26.9	2.50	.282	.077
56-1	BPU	14.7	0	0	58.6	--	1.68	.161	--
2			40	0	74.6	16.0	2.14	.192	.031

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
56-3	BPU	14.7	80	0	77.6	19.0	2.40	.196	.035
4			0	80	68.1	9.5	1.73	.189	.028
5			40	80	85.9	27.3	2.08	.207	.046
6			80	80	95.2	36.6	2.33	.233	.072
2	BDI		40	0	75.3	16.7	2.26	.205	.044
3			80	0	78.2	19.6	2.38	.203	.042
4			0	80	63.7	5.1	1.67	.173	.012
5			40	80	78.4	19.8	2.07	.205	.044
6			80	80	86.3	27.7	2.26	.228	.067
57-1	BPU	11.3	0	0	51.7	--	2.37	.140	--
2		11.3	40	0	54.2	2.5	2.43	.144	.004
3		11.3	80	0	57.3	5.6	2.50	.144	.004
4		12.4	0	80	99.6	47.9	2.45	.270	.130
5		12.4	40	80	118.2	66.5	2.59	.315	.175
6		12.4	80	80	111.1	59.4	2.65	.303	.163
2	BDI	11.3	40	0	58.1	6.4	2.50	.157	.017
3		11.3	80	0	51.3	- 0.4	2.48	.133	-.007
4		12.4	0	80	99.4	47.7	2.53	.253	.113
5		12.4	40	80	111.8	60.1	2.61	.262	.122
6		12.4	80	80	105.3	53.6	2.55	.247	.107
58-1	BPU	11.2	0	0	69.6	--	2.33	.201	--
2			40	0	76.7	7.1	2.37	.186	-.015
3			80	0	73.9	4.3	2.50	.186	-.015
4			0	80	73.7	4.1	2.10	.230	.029
5			40	80	97.1	27.5	2.42	.250	.049
6			80	80	99.6	30.0	2.59	.260	.059
2	BDI		40	0	78.1	8.5	2.45	.200	-.001
3			80	0	74.1	4.5	2.49	.182	-.019
4			0	80	73.6	4.0	2.17	.222	.021
5			40	80	87.3	17.7	2.27	.237	.036
6			80	80	96.7	27.1	2.52	.238	.037
59-1	BPU	15.2	0	0	69.6	--	2.55	.210	--
2			0	40	91.5	21.9	2.46	.240	.030
3			0	80	93.9	24.3	2.45	.257	.047
2	BDI		0	40	90.1	20.5	2.50	.239	.029
3			0	80	91.6	22.0	2.44	.249	.039
60-1	BPU	12.5	0	0	59.5	--	2.60	.172	--
2			0	40	103.8	44.3	2.78	.292	.120
3			0	80	116.0	56.5	2.78	.353	.181
2	BDI		0	40	100.6	41.1	2.70	.256	.084
3			0	80	112.4	52.9	2.79	.302	.130

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
61-1	BPU	11.0	0	0	78.6	--	2.66	.200	--
2			0	40	93.3	14.7	2.70	.243	.043
3			0	80	98.5	19.9	2.70	.264	.064
2	BDI		0	40	92.6	14.0	2.73	.234	.034
3			0	80	96.6	18.0	2.68	.250	.050
62-1	BPU	16.3	0	0	13.3	--	2.13	.142	--
2			0	30	40.5	27.2	1.99	.173	.031
3			0	60	51.0	37.7	1.96	.189	.047
63-1	BDI	11.1	0	0	53.8	--	2.06	.260	--
2		12.4	120	0	83.6	29.8	2.73	.284	.024
3		11.1	0	120	43.0	-10.8	1.91	.232	-.028
4		12.4	120	120	95.3	41.5	2.64	.321	.061
64-1	BPU	12.1	0	0	86.7	--	2.91	.318	--
2			120	0	89.6	2.9	3.06	.308	-.010
3			0	120	89.4	2.7	2.74	.354	.036
4			120	120	86.8	0.1	2.97	.343	.025
65-1	BDI	12.1	0	0	89.8	--	3.06	.258	--
2			120	0	89.8	0.0	3.04	.265	.007
3			0	120	98.4	8.6	2.97	.286	.028
4			120	120	102.5	12.7	2.97	.287	.029
66-1	BPU	13.9	0	0	116.8	--	2.63	.254	--
2			120	0	125.3	8.5	2.78	.278	.024
3			0	120	128.8	12.0	2.58	.315	.061
4			120	120	132.6	15.8	2.78	.328	.074
67-1	BPU	12.4	0	0	80.5	--	2.55	.287	--
2			120	0	95.2	14.7	2.84	.290	.003
3			0	120	89.0	8.5	2.48	.353	.066
4			120	120	106.5	26.0	2.80	.352	.065
68-1	BPU	12.3	0	0	80.7	--	2.68	.337	--
2			120	0	94.0	13.3	3.06	.326	-.011
3			0	120	83.6	2.9	2.68	.372	.035
4			120	120	93.2	12.5	2.96	.347	.010
71-1	BDI	14.0	0	0	88.6	--	2.15	.265	--
2			60	0	106.8	18.2	2.21	.260	-.005
3			120	0	101.9	13.3	2.36	.265	.000
4			0	60	91.7	3.1	2.05	.282	.017

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
71-5	BDI	14.0	60	60	110.1	21.5	2.30	.290	.025
6			120	60	113.3	24.7	2.48	.280	.015
7			120	120	114.0	25.4	2.46	.310	.045
72-1	BPU	13.7	0	0	24.2	--	1.62	.199	--
2			60	0	31.3	7.1	2.21	.165	-.034
3			120	0	26.7	2.5	2.45	.178	-.021
4			180	0	33.0	8.8	2.56	.186	-.013
5			0	60	15.4	- 8.8	1.24	.202	.003
6			60	60	45.9	21.7	1.95	.225	.026
7			120	60	65.0	40.8	2.39	.255	.056
8			120	120	56.7	32.5	2.28	.272	.073
9			180	120	59.1	34.9	2.34	.290	.091
73-1	BPU	11.9	0	0	63.0	--	2.48	.295	--
2			60	0	72.0	9.0	2.63	.265	-.030
3			120	0	88.5	25.5	2.88	.295	.000
4			180	0	79.0	16.0	2.84	.285	-.010
5			0	60	62.0	- 1.0	2.21	.260	-.035
6			60	60	86.0	23.0	2.66	.285	-.010
7			120	60	85.0	22.0	2.78	.290	-.005
8			120	120	93.5	30.5	2.76	.318	.023
9			180	120	90.5	27.5	2.78	.310	.015
77-1	BPU	17.3	0	0	110.6	--	3.04	.286	--
2			40	0	116.0	5.4	2.98	.289	.003
3			80	0	109.0	- 1.6	3.05	.290	.004
4			0	40	110.4	- 0.2	2.88	.293	.007
5			40	40	114.6	4.0	2.90	.317	.031
6			80	40	113.7	3.1	3.02	.301	.015
7			0	80	118.4	7.8	2.80	.303	.017
8			40	80	117.5	6.9	2.96	.310	.024
9			80	80	117.0	6.4	3.02	.316	.030
78-1	BDI	9.0	0	0	42.0	--	1.71	.150	--
2	HL		40	0	56.2	14.2	2.05	.154	.004
3			80	0	63.6	21.6	2.17	.158	.008
4			0	40	53.4	11.4	1.57	.172	.022
5			40	40	78.2	36.2	2.22	.233	.083
6			80	40	83.8	41.8	2.26	.224	.074
7			0	80	53.7	11.7	1.66	.177	.027
8			40	80	79.6	37.6	2.00	.220	.070
9			80	80	82.2	40.2	2.22	.240	.090

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
79-1	BDI	9.3	0	0	71.1	--	2.14	.244	--
2	HL		40	0	75.5	4.4	2.39	.261	.017
3			80	0	81.8	10.7	2.43	.274	.030
4			0	40	81.1	10.0	2.12	.263	.019
5			40	40	86.1	15.0	2.47	.291	.047
6			80	40	85.5	14.4	2.42	.291	.047
7			0	80	71.0	- 0.1	2.52	.287	.043
8			40	80	81.4	10.3	2.16	.252	.008
9			80	80	86.3	15.2	2.57	.308	.064
81-1	BDI	12.0	0	0	75.5	--	2.87	.286	--
2			60	0	85.8	10.3	3.04	.281	-.005
3			0	60	72.2	- 3.3	2.76	.303	.017
4			60	60	87.8	12.3	3.00	.305	.019
82-1	BDI	12.4	0	0	79.8	--	3.08	.228	--
2			60	0	81.2	1.4	3.17	.234	.006
3			0	60	96.8	17.0	3.11	.298	.070
4			60	60	104.0	24.2	3.28	.301	.073
83-1	BDI	18.8	0	0	117.0	--	2.87	.318	--
2			60	0	124.3	7.3	2.94	.316	-.002
3			0	60	114.0	- 3.0	2.69	.320	.002
4			60	60	123.5	6.5	2.93	.316	-.002
84-1	BPU	9.1	0	0	60.5	--	3.14	.250	--
2			60	0	57.0	- 3.5	2.94	.248	-.002
3			0	60	76.0	15.5	3.00	.264	.014
4			60	60	77.5	17.0	2.86	.283	.033
85-1	BPU	12.1	0	0	70.8	--	2.28	.262	--
2		14.0	60	0	97.9	27.1	2.76	.298	.036
3		12.8	0	60	69.0	- 1.8	2.46	.290	.028
4		14.0	60	60	98.3	27.5	2.52	.269	.007
86-1	BPU	14.1	0	0	116.9	--	3.23	.336	--
2			60	0	118.3	1.4	3.27	.338	.002
3			0	60	117.3	0.4	3.21	.356	.020
4			60	60	119.3	2.4	3.26	.363	.027
87-1	BDI	10.8	0	0	77.4	--	2.99	.256	--
2			60	0	80.1	2.7	3.18	.246	-.010
3			0	60	86.0	8.6	3.12	.278	.022
4			60	60	94.9	17.5	3.26	.278	.022

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
88-1	BDI	12.4	0	0	89.0	--	2.64	.271	--
2			60	0	100.7	11.7	2.93	.313	.042
3			0	60	95.1	6.1	2.72	.301	.030
4			60	60	98.8	9.8	2.87	.306	.035
89-1	BPU	13.3	0	0	80.8	--	2.12	.206	--
2		14.2	60	0	107.2	26.4	2.82	.249	.043
3		13.3	0	60	88.5	7.7	2.15	.228	.022
4		14.2	60	60	120.2	39.4	2.61	.266	.060
91-1	BPU	16.1	0	0	83.0	--	3.18	.231	--
2			0	30	91.6	8.6	3.04	.261	.030
3			0	60	94.7	11.7	3.00	.269	.038
93-1	BPU	19.3	0	0	107.7	--	2.41	.219	--
2			30	0	111.8	4.1	2.39	.206	-.013
3			0	30	108.6	0.9	2.22	.209	-.010
4			30	30	118.1	10.4	2.32	.223	.004
94-1	BDI	14.2	0	0	98.2	--	2.03	.299	--
2			0	30	98.0	- 0.2	2.44	.319	.020
98-1	BDI	13.8	0	0	98.1	--	3.01	.284	--
2			60	0	103.4	5.3	2.96	.281	-.003
3			0	60	106.6	8.5	3.06	.335	.051
4			60	60	107.7	9.6	3.09	.340	.056
99-1	BDI	13.9	0	0	95.3	--	3.21	.372	--
2			60	0	96.5	1.2	3.06	.367	-.005
3			0	60	98.8	3.5	3.27	.372	.000
4			60	60	102.2	6.9	3.19	.334	-.038
101-1	BPU	10.6	0	0	89.8	--	3.20	.307	--
2			0	30	97.1	7.3	3.22	.333	.026
3			0	60	96.9	7.1	3.13	.346	.039
1	BDI		0	0	91.1	--	3.20	.312	--
2			0	30	90.8	- 0.3	3.22	.325	.013
3			0	60	95.2	4.1	3.13	.340	.028
102-1	BPU	12.1	0	0	89.1	--	3.05	.366	--
2			0	30	92.3	3.2	3.01	.384	.018
3			0	60	96.5	7.4	2.99	.402	.036
1	BDI		0	0	87.3	--	3.05	.376	--
2			0	30	91.9	4.6	3.01	.389	.013
3			0	60	93.3	6.0	2.99	.386	.010

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
107-1	BPU	18.2	0	0	50.0	--	1.74	.215	--
2			40	0	75.6	25.6	2.34	.253	.038
3			80	0	83.2	33.2	2.40	.246	.031
4			0	40	58.4	8.4	1.74	.232	.017
5			40	40	74.8	24.8	2.12	.252	.037
6			80	40	83.4	33.4	2.45	.265	.050
7			0	80	55.3	5.3	1.74	.240	.025
8			40	80	72.4	22.4	2.07	.270	.055
9			80	80	100.4	50.4	2.48	.312	.097
109-1	BDI	13.2	0	0	114.0	--	2.66	.254	--
2			40	0	110.3	- 3.7	2.75	.260	.006
3			80	0	119.9	5.9	2.83	.268	.014
4			0	40	104.4	- 9.6	2.60	.258	.004
5			40	40	119.0	5.0	2.74	.267	.013
6			80	40	122.2	8.2	2.80	.274	.020
110-1	BDI	12.8	0	0	91.2	--	3.14	.308	--
2			40	0	88.0	- 3.2	3.10	.301	-.007
3			80	0	91.0	- 0.2	3.16	.314	.006
4			0	40	86.4	- 4.8	3.15	.315	.007
5			40	40	91.8	0.6	3.14	.314	.006
6			80	40	89.6	- 1.6	3.19	.319	.011
111-1	BDI	12.5	0	0	93.1	--	2.60	.249	--
2			40	0	100.4	7.3	2.70	.272	.023
3			80	0	100.6	7.5	2.68	.262	.013
4			0	40	99.6	6.5	2.62	.278	.029
5			40	40	103.8	10.7	2.71	.290	.041
6			80	40	98.8	5.7	2.74	.289	.040
112-1	BDI	13.2	0	0	102.8	--	2.96	.268	--
2			40	0	102.8	0.0	3.09	.240	-.028
3			80	0	110.1	7.3	2.98	.266	-.002
4			0	40	115.7	12.9	2.96	.271	.003
5			40	40	111.0	8.2	2.84	.270	.002
6			80	40	110.9	8.1	2.94	.277	.009
113-1	BDI	13.5	0	0	70.1	--	2.68	.311	--
2			40	0	81.6	11.5	2.73	.324	.013
3			80	0	85.3	15.2	2.81	.314	.003
4			0	40	87.7	17.6	2.68	.326	.015
5			40	40	92.6	22.5	2.78	.320	.009
6			80	40	97.0	26.9	2.82	.319	.008

Table 42. (Continued)

Plot no.[d]	P meth.[e]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Δyield[c]	Leaf content[c] %N	Leaf content[c] %P	Leaf content[c] Δ%P
114-1	BDI	12.0	0	0	100.8	--	2.62	.281	--
2			40	0	108.4	7.6	2.68	.287	.006
3			80	0	98.8	- 2.0	2.78	.274	-.007
4			0	40	102.2	1.4	2.69	.291	.010
5			40	40	109.4	8.6	2.75	.300	.019
6			80	40	106.2	5.4	2.84	.294	.013
116-1	BDI	13.4	0	0	60.2	--	2.76	.253	--
2			0	30	66.4	6.2	2.68	.265	.012
3			0	60	66.7	6.5	2.72	.276	.023
119-1	BDI	10.2	0	0	79.0	--	2.86	.268	--
2			150	0	77.6	- 1.4	2.72	.262	-.006
3			0	90	81.6	2.6	2.86	.284	.016
4			150	90	90.3	11.3	2.84	.292	.024
5			0	0	76.3	--	2.84	.245	--
6			0	60	83.0	6.7	2.68	.278	.033
7			0	120	87.3	11.0	2.78	.296	.051
120-1	BDI	13.5	0	0	98.4	--	2.48	.205	--
2			150	0	91.4	- 7.0	2.63	.206	.001
3			0	90	76.9	-21.5	2.18	.210	.005
4			150	90	123.9	25.5	2.65	.250	.045

Table 43. Method of P application, row fertilizer application, stand level, fertilizer treatment, yield and N and P leaf contents of the individual treatments of the experiments not used in the multiple regression analyses

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
6-1	BPU	R	10.2	0	0	72.9	1.98	.200
2				60	0	90.9	2.48	.236
3				0	60	68.4	1.90	.200
4				60	60	91.7	2.54	.262
1			14.1	0	0	61.6	1.61	.170
2				60	0	93.0	2.28	.212
3				0	60	58.4	1.57	.172
4				60	60	88.1	2.29	.234
7-1	BPU	R	9.7	0	0	52.6	2.74	.258
2				60	0	61.0	2.86	.260
3				0	60	54.0	2.52	.275
4				60	60	64.8	2.79	.295
10-1	BPU	R	12.8	0	0	52.5	2.18	.169
2				40	0	57.4	2.44	.171
3				0	40	55.8	2.10	.192
4				40	40	68.4	2.44	.206

[a]Mean stand level of all treatments in thousands of stalks per acre if listed once per experiment; if fertilizer had a significant effect on stand levels, stands are listed for each treatment.

[b]First figure refers to pounds of N per acre; second figure is the pounds of P_2O_5 per acre.

[c]Yields in bushels per acre and N and P percentages for each experiment are at the K level or levels given in Table 41.

[d]First figure refers to experiment number and is listed once; second figure refers to treatment number.

[e]Method of P application: BPU = broadcast and plowed under, BDI = broadcast and disked in, HL = hard-ground listed, LL = loose-ground listed, SD = side-dressed. Method(s) listed once per experiment.

[f]Broadcast treatments without (O) or with (R) hill or row fertilizer.

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
12-1	BPU	R	11.2	0	0	66.7	2.16	.282
2				60	0	81.2	2.50	.289
3				0	60	65.5	2.11	.342
4				60	60	88.2	2.37	.309
13-1	BPU	R	13.9	0	0	67.3	2.64	.280
2				40	0	67.7	2.72	.307
3				0	40	68.7	2.63	.302
4				40	40	72.8	2.60	.307
18-1	BDI	R	14.6	0	0	69.8	1.90	.222
2				60	0	95.0	2.52	.243
3				0	60	69.7	1.88	.230
4				60	60	100.9	2.45	.280
19-1	BDI	R	12.1	0	0	84.6	2.55	.285
2				60	0	91.4	2.68	.298
3				0	60	86.8	2.56	.317
4				0	120	87.4	2.52	.331
5				60	60	97.0	2.67	.308
6				60	120	96.8	2.72	.332
20-1	BDI	R	13.8	0	0	81.5	2.36	.230
2				0	40	86.3	2.32	.254
3				0	80	89.0	2.20	.268
21-1	BPU	R	13.4	0	0	75.8	2.18	.245
2				0	40	75.3	1.98	.269
3				0	80	75.8	1.95	.278
22-1	BPU	0	13.0	0	0	51.8	2.36	.253
2				40	0	62.3	2.69	.263
3				80	0	65.2	2.84	.285
4				0	40	52.1	2.14	.267
5				40	40	63.6	2.68	.287
6				80	40	64.7	2.97	.302
7				0	80	57.3	2.21	.285
8				40	80	61.1	2.76	.300
9				80	80	62.3	2.79	.310
1		R		0	0	60.8	2.26	.252
2				40	0	63.3	2.68	.272
3				80	0	64.2	2.78	.287
4				0	40	57.9	2.14	.263
5				40	40	64.1	2.55	.287

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
6	BPU	R	13.0	80	40	66.7	2.70	.297
7				0	80	55.4	2.12	.282
8				40	80	65.9	2.51	.315
9				80	80	63.0	2.62	.317
23-1	BPU	R	11.4	0	0	66.0	2.64	.262
2				40	0	75.4	2.80	.268
3				80	0	71.2	2.90	.270
4				0	40	71.2	2.76	.282
5				40	40	77.0	2.81	.285
6				80	40	73.8	2.82	.298
7				0	80	65.8	2.31	.278
8				40	80	76.9	2.62	.315
9				80	80	74.6	2.79	.295
24-1	BPU	R	13.6	0	0	83.4	2.56	.275
2				40	0	88.8	2.88	.293
3				80	0	89.5	2.89	.292
4				0	40	84.3	2.63	.285
5				40	40	91.2	2.87	.288
6				80	40	91.0	2.79	.305
7				0	80	80.3	2.53	.290
8				40	80	90.3	2.72	.298
9				80	80	93.9	2.86	.312
25-1	BPU	R	10.3	0	0	15.0	2.11	.120
2				40	0	13.5	2.38	.117
3				80	0	15.9	2.35	.130
4				0	40	24.6	1.67	.157
5				40	40	39.2	2.33	.178
6				80	40	44.9	2.61	.200
7				0	80	26.8	1.57	.178
8				40	80	41.7	2.05	.200
9				80	80	57.9	2.64	.248
31-1	BDI	R	12.9	0	0	70.2	1.78	.192
2				60	0	99.2	2.41	.234
3				0	60	58.7	1.55	.172
4				60	60	96.0	2.22	.230
5				120	120	117.7	2.54	.292
32-1	BPU	R	14.5	0	0	110.7	2.95	.288
2				60	0	110.8	3.06	.283
3				60	60	123.5	3.04	.339

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
32-4	BPU	R	14.5	120	60	125.5	3.10	.313
5				120	120	122.4	2.99	.336
6				180	120	121.8	3.13	.317
35-1	BPU	R	11.5	0	0	87.0	2.83	.250
2				40	0	90.9	2.96	.240
3				80	0	88.5	3.07	.258
4				0	40	95.2	2.82	.269
5				40	40	93.3	2.88	.270
6				80	40	92.2	2.88	.286
7				0	80	92.0	2.80	.277
8				40	80	98.4	2.92	.294
9				80	80	100.2	3.06	.290
36-1	BPU	R	12.2	0	0	75.6	3.00	.216
2				40	0	80.6	3.20	.234
3				80	0	86.9	3.20	.243
4				0	40	93.1	3.06	.242
5				40	40	96.6	3.15	.252
6				80	40	100.0	3.08	.249
7				0	80	87.5	2.75	.234
8				40	80	99.3	3.12	.265
9				80	80	107.0	3.16	.254
37-1	BPU	R	9.8	0	0	65.8	2.46	.226
2				40	0	72.5	2.86	.239
3				80	0	77.3	2.92	.246
4				0	40	65.8	2.26	.222
5				40	40	69.2	2.66	.241
6				80	40	73.4	2.98	.275
7				0	80	62.7	2.36	.246
8				40	80	70.3	2.74	.254
9				80	80	71.3	2.95	.283
41-1	BPU	O	12.1	0	0	105.9	2.34	.250
2				40	0	106.1	2.38	.248
3				80	0	108.9	2.52	.252
4				0	40	109.6	2.25	.270
5				40	40	103.8	2.43	.265
6				80	40	112.4	2.51	.275
7				0	80	98.8	2.27	.281
8				40	80	106.8	2.47	.303
9				80	80	112.9	2.63	.302
2	BDI			40	0	108.8	2.49	.254

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
41-3	BDI	0	12.1	80	0	109.5	2.55	.250
4				0	40	102.2	2.25	.250
5				40	40	114.3	2.43	.250
6				80	40	109.1	2.53	.266
7				0	80	102.2	2.43	.261
8				40	80	103.6	2.42	.267
9				80	80	107.4	2.54	.277
44-1	BPU	R	13.0	0	0	124.6	3.12	.271
2				0	40	138.4	3.12	.313
3				0	80	135.9	3.09	.326
1	BDI			0	0	127.0	3.12	.269
2				0	40	133.2	3.12	.293
3				0	80	129.8	3.09	.332
48-1	BPU	R	14.1	0	0	70.9	2.27	.208
2				60	0	100.0	2.87	.238
3				120	0	99.9	2.92	.242
4				180	0	104.5	2.86	.245
5				0	120	71.7	2.12	.208
6				60	120	96.8	2.74	.241
7				120	120	103.5	2.74	.259
8				180	120	114.5	3.00	.278
52-1	BPU	0	14.2	0	0	54.0	2.44	.238
2				60	0	63.0	2.80	.250
3				120	0	58.0	2.74	.235
4				180	0	61.5	2.72	.238
5				0	60	42.0	2.36	.248
6				60	60	67.5	2.60	.285
7				120	60	66.0	2.62	.292
8				180	60	67.5	2.80	.290
9				120	120	82.0	2.82	.290
10				180	120	84.0	2.78	.308
63-1	BDI	R	11.1	0	0	61.9	2.02	.263
2			12.4	120	0	87.9	2.84	.285
3			11.1	0	120	54.7	2.32	.247
4			12.4	120	120	100.6	2.74	.319
64-1	BPU	R	12.1	0	0	87.2	2.74	.313
2				120	0	92.5	2.84	.317
3				0	120	85.4	2.54	.340
4				120	120	91.4	2.86	.353

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
65-1	BDI	R	12.8	0	0	97.8	3.05	.258
2				120	0	98.0	3.02	.262
3				0	120	111.2	3.03	.291
4				120	120	110.0	3.01	.289
66-1	BPU	R	13.9	0	0	130.0	2.73	.275
2				120	0	127.6	2.78	.284
3				0	120	124.3	2.61	.308
4				120	120	137.6	2.74	.312
67-1	BPU	R	12.5	0	0	89.5	2.54	.295
2			12.7	120	0	102.5	2.92	.304
3			13.4	0	120	96.5	2.57	.342
4			12.8	120	120	109.0	2.93	.348
68-1	BPU	R	12.3	0	0	85.2	2.60	.345
2				120	0	96.0	3.02	.325
3				0	120	86.5	2.61	.376
4				120	120	97.2	3.03	.362
69-1	BDI	R	12.1	0	0	109.5	2.81	.354
2				120	0	114.3	2.89	.342
3				0	120	109.0	2.81	.395
4				120	120	117.2	2.88	.379
70-1	BDI	R	13.4	0	0	87.0	1.84	.193
2				60	0	99.0	2.18	.200
3				120	0	100.9	2.32	.232
4				180	0	99.1	2.34	.225
5				0	60	89.8	1.92	.255
6				60	60	98.8	2.20	.260
7				120	60	109.5	2.32	.260
8				120	120	103.9	2.11	.310
9				180	120	98.0	2.44	.320
74-1	BPU	0	13.2	0	0	74.3	1.86	.190
2				60	0	90.5	2.04	.216
3				120	0	94.7	2.14	.204
4				180	0	88.3	2.20	.186
5				0	60	75.7	1.66	.161
6				60	60	89.0	2.08	.208
7				120	60	88.9	2.28	.225
8				120	120	94.8	2.22	.225
9				180	120	95.3	2.34	.232

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
75-1	BPU	0	11.9	0	0	68.5	2.44	.265
2				60	0	93.8	2.57	.280
3				120	0	77.9	2.58	.285
4				180	0	73.7	2.73	.270
5				0	60	67.0	2.04	.255
6				60	60	83.2	2.50	.302
7				120	60	82.6	2.64	.308
8				180	60	82.8	2.68	.300
9				120	120	81.6	2.40	.300
10				180	120	82.6	2.58	.325
76-1	BPU	0	19.3	0	0	26.1	1.53	.247
2				40	0	41.4	1.87	.239
3				80	0	51.5	2.32	.263
4				160	0	59.5	2.76	.282
5				0	40	23.3	1.59	.254
6				40	40	40.1	1.91	.255
7				80	40	49.3	2.31	.282
8				160	40	56.0	2.65	.309
9				0	80	24.8	1.71	.275
10				40	80	44.0	1.99	.285
11				80	80	55.4	2.37	.293
12				160	80	55.2	2.77	.304
80-1	BPU,LL	0	10.3	0	0	42.8	1.27	.193
2				40	0	81.7	1.86	.253
3				80	0	99.7	2.22	.282
4				0	40	33.3	1.25	.175
5				40	40	71.4	1.59	.206
6				80	40	107.1	2.32	.288
7				0	80	37.6	1.30	.241
8				40	80	60.6	1.71	.222
9				80	80	102.2	2.34	.300
81-1	BDI	R	12.4	0	0	86.8	2.86	.293
2				60	0	92.0	3.06	.290
3				0	60	86.8	2.75	.293
4				60	60	92.8	2.98	.297
82-1	BDI	R	12.9	0	0	90.0	3.16	.243
2				60	0	93.5	3.23	.252
3				0	60	109.0	3.14	.300
4				60	60	111.8	3.32	.314

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
83-1	BDI	R	18.8	0	0	140.0	2.80	.326
2				60	0	142.0	2.94	.322
3				0	60	124.0	2.69	.308
4				60	60	137.2	2.96	.325
84-1	BPU	R	10.6	0	0	86.0	3.02	.258
2				60	0	94.5	2.96	.251
3				0	60	89.0	3.05	.288
4				60	60	91.5	2.96	.281
85-1	BPU	R	12.8	0	0	72.7	2.22	.291
2			14.0	60	0	100.6	2.74	.293
3			12.8	0	60	69.0	2.16	.269
4			14.0	60	60	101.2	2.60	.296
86-1	BPU	R	14.1	0	0	119.2	3.19	.340
2				60	0	118.7	3.28	.330
3				0	60	125.7	3.21	.360
4				60	60	126.4	3.25	.368
87-1	BDI	R	11.6	0	0	94.4	2.93	.256
2				60	0	100.1	3.16	.286
3				0	60	106.5	3.06	.281
4				60	60	111.4	3.10	.281
88-1	BDI	R	12.4	0	0	96.4	2.75	.281
2				60	0	108.6	2.93	.296
3				0	60	101.0	2.73	.297
4				60	60	108.7	2.83	.304
89-1	BPU	R	13.3	0	0	96.2	2.38	.226
2			14.2	60	0	116.5	2.89	.252
3			13.3	0	60	88.2	2.25	.220
4			14.2	60	60	117.5	2.92	.274
90-1	SD	0	14.6	0	0	33.6	1.65	.199
2				60	0	64.7	2.18	.189
3				0	60	33.9	1.55	.196
4				60	60	69.0	2.17	.201
5				0	0	47.6	1.80	.199
6				60	0	81.0	2.35	.219
7				0	60	51.1	1.82	.206
8				60	60	86.8	2.32	.222

Table 43. (Continued)

Plot no.[d]	P Meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
92-1	BPU	R	11.8	0	0	69.8	2.62	.238
2				120	0	75.5	2.81	.257
3				0	60	70.5	2.56	.230
4				120	60	73.5	2.80	.260
95-1	BDI	0	8.2	0	0	56.1	2.76	.302
2				40	0	71.2	2.76	.314
3				80	0	75.2	2.74	.293
4				0	40	61.8	2.76	.312
5				40	40	76.1	2.76	.285
6				80	40	78.7	2.74	.302
7				0	80	65.8	2.76	.312
8				40	80	72.7	2.76	.313
9				80	80	81.3	2.74	.314
96-1	BDI-HL	0	10.0	0	0	43.3	1.91	.181
2				30	0	46.4	2.22	.174
3				60	0	44.0	2.24	.158
4				120	0	39.8	2.38	.163
5				0	30	40.8	1.92	.190
6				30	30	45.8	2.20	.184
7				60	30	47.4	2.20	.193
8				120	30	52.6	2.38	.188
9				0	60	41.8	1.96	.213
10				30	60	45.8	2.02	.210
11				60	60	51.4	2.21	.202
12				120	60	53.9	2.43	.208
1			13.5	0	0	24.2	1.75	.156
2				30	0	35.0	2.13	.152
3				60	0	37.5	2.12	.170
4				120	0	25.8	2.24	.154
5				0	30	28.9	1.77	.176
6				30	30	37.4	1.90	.170
7				60	30	46.8	2.10	.176
8				120	30	39.4	2.39	.154
9				0	60	32.7	1.81	.196
10				30	60	30.4	1.86	.172
11				60	60	49.0	2.17	.187
12				120	60	53.6	2.18	.193
97-1	BDI-LL	0	9.9	0	0	69.0	2.36	.316
2				30	0	69.7	2.40	.293
3				60	0	63.5	2.43	.299
4				120	0	62.4	2.40	.293

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
97-5	BDI-LL	0	9.9	0	30	61.1	2.32	.294
6				30	30	70.1	2.42	.298
7				60	30	60.4	2.45	.299
8				120	30	71.3	2.50	.309
9				0	60	70.6	2.44	.284
10				30	60	63.5	2.39	.296
11				60	60	63.2	2.43	.294
12				120	60	67.3	2.48	.308
1			14.3	0	0	69.4	2.29	.305
2				30	0	75.0	2.37	.281
3				60	0	74.2	2.38	.305
4				120	0	67.8	2.35	.293
5				0	30	68.4	2.30	.293
6				30	30	62.4	2.29	.294
7				60	30	71.0	2.36	.297
8				120	30	72.0	2.42	.302
9				0	60	69.0	2.26	.276
10				30	60	65.6	2.39	.293
11				60	60	60.4	2.28	.281
12				120	60	69.3	2.44	.293
98-1	BDI	R	13.8	0	0	105.0	2.80	.271
2				60	0	114.4	3.04	.303
3				0	60	108.8	2.80	.322
4				60	60	111.9	3.03	.330
99-1	BDI	R	13.9	0	0	107.0	3.24	.351
2				60	0	108.7	3.24	.352
3				0	60	109.0	3.25	.371
4				60	60	112.1	3.15	.373
100-1	BDI	R	11.7	0	0	79.1	2.77	.272
2				60	0	91.8	2.97	.268
3				0	60	82.5	2.79	.297
4				60	60	95.6	3.04	.317
103-1	BPU	R	10.6	0	0	73.5	3.00	.309
2				40	0	74.1	3.10	.321
3				80	0	80.9	3.09	.311
4				0	40	78.7	2.96	.320
5				40	40	77.4	2.97	.338
6				80	40	78.2	3.05	.333
7				0	80	80.4	3.07	.352
8				40	80	78.9	3.00	.352
9				80	80	76.3	3.07	.353

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
104-1	BDI	0	13.1	0	0	79.3	2.44	.229
2				40	0	73.0	2.52	.192
3				80	0	88.3	2.62	.256
4				0	40	87.3	2.40	.254
5				40	40	97.8	2.68	.253
6				80	40	92.6	2.60	.248
7				0	80	84.6	2.44	.214
8				40	80	104.6	2.67	.312
9				80	80	90.7	2.50	.288
105-1	BDI	0	10.8	0	0	72.6	2.25	.178
2				60	0	78.0	2.22	.194
3				0	30	88.7	2.30	.206
4				60	30	84.6	2.10	.202
5				0	60	73.4	2.33	.183
6				60	60	82.6	2.27	.205
7				0	90	84.3	2.28	.217
8				60	90	80.6	2.21	.225
106-1	BPU	0	16.4	0	0	92.0	2.54	.250
2				40	0	84.6	2.55	.240
3				80	0	87.6	2.60	.252
4				0	40	88.0	2.37	.238
5				40	40	94.0	2.60	.250
6				80	40	88.1	2.72	.274
7				0	80	84.4	2.44	.257
8				40	80	95.4	2.70	.283
9				80	80	92.4	2.62	.269
1		R	15.6	0	0	94.6	2.52	.238
2				40	0	88.6	2.50	.240
3				80	0	92.4	2.56	.245
4				0	40	88.5	2.38	.250
5				40	40	92.2	2.54	.265
6				80	40	86.1	2.59	.268
7				0	80	86.6	2.50	.268
8				40	80	95.9	2.58	.278
9				80	80	94.1	2.67	.288
107-1	BPU	R	16.9	0	0	58.0	1.92	.252
2				40	0	83.6	2.27	.255
3				80	0	85.0	2.41	.248
4				0	40	61.2	1.68	.237
5				40	40	81.4	2.10	.252
6				80	40	85.8	2.46	.290

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
107-7	BPU	R	16.9	0	80	64.6	1.84	.250
8				40	80	76.4	2.10	.283
9				80	80	97.8	2.42	.298
108-1	BPU	O	12.3	0	0	23.4	1.58	.162
2				40	0	40.0	2.16	.198
3				80	0	50.8	2.35	.212
4				0	40	23.1	1.36	.184
5				40	40	36.8	2.10	.214
6				80	40	45.0	2.28	.228
7				0	80	14.2	1.23	.166
8				40	80	34.2	2.00	.240
9				80	80	48.2	2.38	.272
1		R		0	0	30.1	1.43	.157
2				40	0	44.4	2.12	.201
3				80	0	55.6	2.12	.206
4				0	80	29.8	1.51	.198
5				40	40	40.3	2.08	.229
6				80	40	45.0	2.28	.240
7				0	80	15.7	1.16	.142
8				40	80	36.4	2.05	.244
9				80	80	45.6	2.30	.280
109-1	BDI	R	13.2	0	0	120.0	2.73	.268
2				40	0	120.4	2.80	.270
3				80	0	121.4	2.90	.273
4				0	40	111.9	2.66	.262
5				40	40	124.9	2.80	.276
6				80	40	125.2	2.82	.278
110-1	BDI	R	12.8	0	0	95.2	3.14	.312
2				40	0	92.9	3.10	.302
3				80	0	95.8	3.12	.304
4				0	40	91.1	3.02	.311
5				40	40	94.4	3.04	.319
6				80	40	94.8	3.15	.307
111-1	BDI	R	12.5	0	0	106.1	2.59	.275
2				40	0	110.6	2.64	.284
3				80	0	107.0	2.76	.278
4				0	40	110.4	2.56	.280
5				40	40	107.0	2.61	.288
6				80	40	107.5	2.56	.274

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
112-1	BDI	R	13.2	0	0	114.9	2.78	.256
2				40	0	113.9	2.84	.247
3				80	0	119.1	2.81	.263
4				0	40	119.5	2.76	.260
5				40	40	118.0	2.85	.267
6				80	40	124.8	2.96	.269
113-1	BDI	R	13.5	0	0	83.2	2.75	.318
2				40	0	90.8	2.76	.319
3				80	0	99.7	2.81	.320
4				0	40	94.8	2.72	.339
5				40	40	98.7	2.66	.324
6				80	40	105.6	2.75	.324
114-1	BDI	R	12.0	0	0	106.4	2.62	.292
2				40	0	105.9	2.85	.298
3				80	0	107.6	2.82	.297
4				0	40	106.5	2.71	.310
5				40	40	100.6	2.77	.286
6				80	40	115.8	2.88	.307
115-1	BDI	R	13.0	0	0	94.1	2.60	.233
2				0	30	97.7	2.65	.256
3				0	60	102.1	2.50	.271
117-1	BDI	0	14.1	0	0	49.2	2.40	.241
2				40	0	53.2	2.51	.226
3				80	0	52.1	2.54	.230
4				0	40	50.4	2.40	.227
5				40	40	56.3	2.58	.245
6				80	40	53.5	2.62	.244
7				0	80	53.9	2.47	.241
8				40	80	52.2	2.53	.250
9				80	80	51.1	2.60	.259
118-1	BPU	0	10.7	0	0	44.5	2.23	.165
2				40	0	50.9	2.34	.171
3				80	0	37.5	2.42	.185
4				0	40	52.5	2.16	.187
5				40	40	50.4	2.38	.212
6				80	40	50.0	2.43	.209
7				0	80	43.0	2.15	.202
8				40	80	39.9	2.32	.224
9				80	80	76.9	2.43	.220

Table 43. (Continued)

Plot no.[d]	P meth.[e]	Row fert.[f]	Stand[a]	Tmt.[b] N	Tmt.[b] P_2O_5	Yield[c]	Leaf content[c] %N	Leaf content[c] %P
118-2	BDI	0	10.7	40	0	46.9	2.31	.168
3				80	0	44.5	2.58	.173
4				0	40	42.4	2.13	.183
5				40	40	46.9	2.26	.176
6				80	40	58.4	2.29	.198
7				0	80	46.7	2.05	.198
8				40	80	39.9	2.30	.205
9				80	80	76.0	2.30	.208

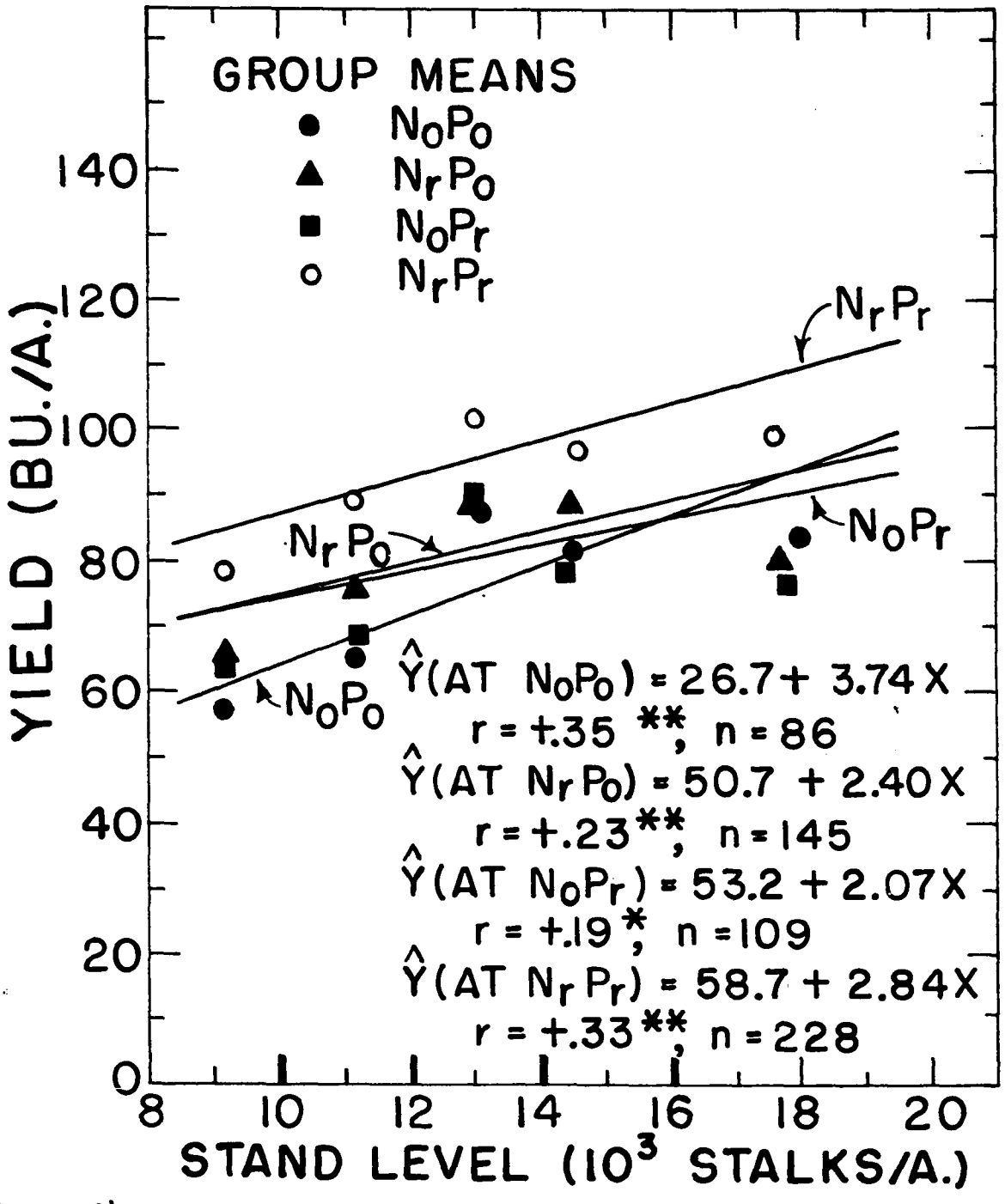

Figure 34. Regressions of the corn yield at the N_0P_0, N_rP_0, N_0P_r and N_rP_r treatments on the stand level (all N and/or P rates)