EFFECTS OF CONTINUED APPLICATION OF NITROGEN AND PHOSPHORUS ON THE CHEMICAL COMPOSITION OF IRRIGATED RICHFIELD SILT LOAM

by

GALEN RAY NIEDENTHAL

B. S., Kansas State University, 1969

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

Approved by:

Larry Murphy
Major Professor

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author would like to express his sincere appreciation to Dr. Larry S. Murphy, major professor, for the suggestion of this problem, and his advice and counseling during the course of study. His assistance in interpreting the data and preparing the manuscript was also greatly appreciated. Thanks is also extended to Dr. William Powers and Dr. David Whitney who served as members of the supervisory committee.

Appreciation is extended to Dr. Roscoe Ellis, Jr. for his advice regarding chemical analysis procedures and to G. W. Wallingford for his suggestions regarding computing techniques and his assistance with carbon analysis procedures.

Sincere thanks are extended to the personnel of the KSU soil fertility laboratory and soil testing laboratory for their assistance with the chemical analysis.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

Table | Page

INTRODUCTION

Substantial increases in agricultural production are necessary to support rapidly growing populations in most areas of the world today. Proper fertilizers, applied at the appropriate rate and time, are essential if needed levels of production are to be achieved and if economic development is to proceed. The inadequate availability of fertilizer today due to the present shortages of natural gas and other energy resources makes proper fertilization techniques even more important.

Nitrogen and phosphorus are two nutrients that have received much concentrated interest in research. Nitrogen supplied to the soil by natural processes is seldom sufficient to produce satisfactory yields of crops. Accordingly, more and more reliance has been placed on nitrogen fertilizers.

Abundant amounts of phosphorus usually exist in soils, but most of it is present in highly insoluble minerals and is unavailable to plants. Even when available P is applied to the soil, it can be rendered unavailable due to reactions between soil components and phosphorus.

The marked increase in the use of N and P fertilizers in recent years has generated growing interest in the effect of these fertilizers on soil chemical properties, especially when applied at high rates over a period of years. The continued use of single nutrient fertilizers may eventually produce a nutrient imbalance in the soil through excessive removal of certain other nutrients. Nitrogen applied at excessive rates or at improper times may increase the probability of nutrient loss through volatilization or through leaching and possible groundwater contamination.

This investigation was part of a long-range study initiated at the Tribune Branch Experiment Station to evaluate the responses of irrigated corn to various rates of nitrogen, phosphorus, and potassium fertilizers. Beginning in 1961, fertilizer was applied broadcast by hand before planting two corn hybrids, using NH_4NO_3 (34-0-0), triple-superphosphate (0-20-0, or 0-46-0 on a P_2O_5 basis), and KCl (0-0-50, or 0-0-60 on a K_2O basis). Rates of application of each element, expressed in kg/ha, were: nitrogen: 0, 45, 90, 134, 179, and 224; phosphorus: 0 and 19; and potassium: 0 and 37. These trials have been continued with the same amount of nitrogen, phosphorus, and potassium applied to each plot each year. In 1968 and 1969, a uniform application of 11 kg/ha of zinc was applied to the corn test area as $ZnSO_4$ to offset a low soil zinc condition as determined by soil tests. Since 1968, an additional 19 kg/ha of P was applied to one-half of each plot area.

Recent corn yields at this location have indicated no significant response to the applied potassium or to the additional 19 kg/ha phosphorus application. Nitrogen applications up to 179 kg/ha have increased grain yields considerably, but 224 kg/ha of nitrogen has not produced greater corn yields than the 179 kg/ha rate.

The portion of the study reported in this thesis was concerned with the effect of the continuous applications of N and P on the chemical properties of the Richfield silt loam soil, and to determine the fate of applied nitrogen not utilized by the corn crop.

REVIEW OF LITERATURE

Soil Fertility Treatment Effects on Total Nitrogen and Organic Carbon

Long-term soil fertility treatments have been shown to have dramatic effects on soil chemical properties (28, 32, 45, 46, 62, 68, 69). Dodge and Jones (28) reported that in one long-term study, there was a continual over-all loss of nitrogen and carbon over the entire 30-year cropping period regardless of cropping system or fertilizer treatment. Fertility treatments had relatively little influence on the nitrogen trends in the soil or on the C/N ratio. Plots with the highest nitrogen content at the beginning of the experiment suffered the greatest losses of nitrogen.

Haas and Evans (32) showed that there was a sharp decline in total N and organic C after a 36-year cropping period in another study. Pratt and Chapman (69) found that there were losses of total nitrogen and organic carbon at the 90-120 cm depth after a 20-year lysimeter investigation. They also reported decreases in exchangeable potassium with depth, and decreases in magnesium content with increasing N treatments.

In arguing against the claim that agricultural fertilization is a leading source of nitrates in our water supplies, Stewart pointed out that the total nitrate-N currently available from the soil organic matter and fertilizer is less than the soil organic matter alone furnished at the beginning of cultivation many years ago (79). Since both total N and organic C are reliable estimates of organic matter content and the content of organic matter is an index of the amount of potentially available nitrogen in a soil, it can be seen that these effects of continuous cropping are of considerable importance.

Soil Reaction Changes and Secondary Effects on Other Soil Chemical Properties

Of the many effects long-term applications of nitrogen fertilizers have on the soil, the most important is probably the general tendency of these materials to alter the surface and subsoil pH (1, 2, 12, 23, 46, 62, 66, 67, 88, 89, 90, 91). Nitrogen carriers have a direct, immediate effect on soil acidity and a residual effect which develops more slowly (88). Residual changes in soil pH may be in the same direction as the immediate change at the time of application, as in the case of ammonium salts and calcium cyanamid; or residual effects may completely reverse direct effects, as in the case of anhydrous ammonia, diammonium phosphate, and materials, such as urea, which release ammonia upon hydrolysis. Clevenger and Willis (23) described the immediate decrease in soil pH upon addition of nitrogen fertilizers as due to a "salt effect". Wolcott came to the same conclusions after his work with several N fertilizers (88, 90, 91).

Residual acidifying effects of most common N fertilizers are generally in the following descending order: mono-ammonium phosphate, ammonium sulfate, ammonium chloride, di-ammonium phosphate, ammonium nitrate = anhydrous ammonia = urea = ureaform (66, 88, 90). Calcium nitrate, sodium nitrate, potassium nitrate, and calcium cyanamid possess a residual basic effect on most soils.

The increased acidity of soils due to continuous applications of nitrogen fertilizers has several indirect effects on other soil chemical properties. Abruna, Pearson, and Elkins (1) found that heavy applications of ammonium nitrate and ammonium sulfate caused severe reduction in exchangeable base level after only one year of applications. He reported that exchangeable K was lost from the soil faster than other bases. An indication of a subsoil zone of accumulation of bases leached out of upper horizons was observed.

Adams et al. (2) found that annual applications of N fertilizer exceeding 224 kg/ha reduced soil pH, and that the higher the N rates, the deeper the profile pH was affected. The movement of calcium and magnesium downward to the 30-45 cm zone confirmed the effect of pH on these cations. In another study, ammonium sulfate applied at a rate of 38 kg N/ha lowered soil pH from 7.4 to 6.0 after 5 years (12). The effect of ammonium nitrate was less pronounced, and calcium nitrate had no influence on pH. The pH changes only had slight effects on exchangeable and soluble cations.

The use of high rates of residually acid nitrogen fertilizer caused appreciable downward movement of calcium and magnesium salts in a study by Hiltbold et al. (35). In a Michigan study (91) the effects of ammonium sulfate and calcium nitrate on exchangeable base status were compared. Total exchangeable bases (K + Ca + Mg) declined consistently from year to year at all sampling depths, regardless of treatment.

Nitrogen sources can indirectly effect micronutrient availability because of changes in soil pH. In a study reported by Leo, Odland, and Bell (35), long continued use of ammonium sulfate increased soil acidity and also increased the solubility of toxic aluminum. There was also slight downward movement of organic matter, which increased subsoil organic matter content, CEC, and led to a wider C/N ratio in the subsoil. Viets (84) found that poor aeration (low redox potential) coupled with low pH increased the amount of water-soluble manganese and iron in soils but had little effect on zinc and copper. Copper availability is dependent upon soil pH but does not normally increase appreciably until pH falls below 5.0. Manganese availability increases markedly when the pH falls below 5.5. Field studies with corn in Michigan showed that acidifying nitrogen carriers increased the uptake of manganese, zinc, and boron, while tending to depress the uptake of molybdenum and copper (90).

Owensby et al. (62) observed that high rates of nitrogen applied to bromegrass lowered soil pH in the upper 15 cm of the soil profile. In the 15-30 cm depth, only the 224 kg/ha N rate lowered the pH significantly. Exchangeable potassium decreased with nitrogen rate initially, but increased at the higher rates in the upper portions of the soil profile. This increased availability was linked to increased acidity at those levels.

Boawn et al. (12) showed that high rates of applied N had no pronounced influence on P availability, but the resultant lowered pH did increase the availability of manganese. Very low soil pH may decrease P availability due to the formation of insoluble iron and aluminum compounds containing phosphorus. Pierre and others (67) noticed that with high nitrogen application rates developed acidity was much less than the theoretical amount expected. They reported that this was due to the low excess base compared with nitrogen in the harvested crop. They also speculated that there were large losses of nitrogen due to denitrification without an equivalent loss of bases. Dancer, Peterson, and Chesters (27) found that as soil pH decreased, the rate of nitrate accumulation decreased and the length of the delay period before nitrate-nitrogen started to accumulate was increased.

In a study by Broadbent and Tyler (19) utilizing ammonium chloride and potassium nitrate, nitrogen immobilized in the soil from the ammonium source increased as pH increased, whereas the reverse was true of the nitrate source. These results appear to be related to the physiological acidity or alkalinity of the nitrogen source. Use of residually acidic fertilizers on a calcareous soil tends to lower pH, but also increases the probability of immobilizing some available nitrogen.

Cornfield (26) found that acid soils tend to accumulate organic nitrogenous residues to a greater extent than do soils of high pH and that the nitrogen in such residues tends to mineralize readily if soil pH is increased. He also found that nitrate accumulation occurred more rapidly in soils having a pH greater than 6.5. Ammonium accumulation was generally high in acid and low in neutral and alkaline soils (25). Generally, soils that fix ammonium under moist conditions have low nitrification values.

While the effect of nitrification on soil acidity has received considerable attention, any effect that nitrogen volatilization might have on acidity has been ignored. Hiltbold and Adams (35) noted that nitrification of an added ammonium salt creates acidity equivalent to the ammonium oxidized plus the anion with which it is associated. Gaseous loss of ammonia or volatilization of nitrogen during nitrification effect a removal of potential acidity equivalent to the nitrogen lost. Denitrification of nitrate results in formation of OH^- equivalent to the nitrate reduced and volatilized. The frequent unaccounted losses as well as low recoveries of applied nitrogen by plants indicate that volatilization may appreciably effect the soil acidity resulting from N fertilizers.

As soils become more acidic over a period of time due to nitrogen fertilization, the leachates in the upper horizons tend to show greater acidity than do the soils themselves. As these leachates move downward, the lower depths decrease in pH also. On acid-sensitive crops, low pH may inhibit root growth, thus allowing less utilization of nitrogen deep in the soil profile (2).

Abruna (1) observed that excess soil acidity from long term nitrogen applications may also effect activity of soil microorganisms. The optimum pH of nitrification is about 7.5 to 9.0, so nitrification may be retarded if the soil pH is decreased too much.

Continuous nitrogen applications have been shown to have secondary effects on the availability of soil phosphorus. Grunes (31) found that additions of nitrogen fertilizers to the soil can have both a salt effect and a pH effect on phosphorus availability. In calcareous soils, the salt increased the solubility and hydrolysis of the calcium carbonates to produce a higher calcium ion concentration which in turn reduced the phosphate concentration. Residually-acidic N fertilizers slowed down reversion of soluble phosphorus fertilizers to a more insoluble form and brought more phosphorus into solution from the reaction product of the soil and the P fertilizer.

Lorenz and Johnson (49) found that the physiologically acid ammonium salt, $(NH_4)_2SO_4$, effectively released native soil phosphate better than NH_4NO_3 on a fine sandy loam soil with a pH of 7.8. Olsen et al. (60) discovered that phosphorus solubility in calcareous soils in Colorado increased rapidly as the soil pH decreased. Lowering the pH of alkaline soils was found to increase the phosphorus in solution (21, 68).

Owensby et al. (62) found that high nitrogen rates increased the availability of phosphorus in the surface 15 cm of soil in a study in Kansas. Rennie and Soper (72) found that increased utilization of phosphorus occurred only when the applied nitrogen was in the ammonium form. Nitrate sources of N were relatively ineffective. They attributed this to the fact that the ammonium ion indirectly influences the plants' ability to take up phosphorus, but does not effect the availability of the applied phosphorus fertilizer. At higher soil pH levels (7-9), HPO_4^{-2} is the dominant ionic form of P, and is less readily absorbed by most plants than the $H_2PO_4^-$ ionic form found within the pH range 5-7.

<u>Effects of Continuous Fertilization on Nitrate Accumulation and Leaching</u>

Oxidation of ammonia to nitrate results in replacement of the basic ion by hydrogen and the conversion of nitrogen to a mobile form in which it may accompany soil bases in leaching (35). Much work has been conducted involving accumulations of nitrate in the soil. Bates and Tisdale (9) found that the form in which nitrates are added to the soil, the nature of the accompanying ion, and the physical placement of the salt in the soil all contribute to the net movement of nitrate-nitrogen in the soil. Upward movement of this ion is influenced by the movement of capillary water resulting from surface evaporation.

Gardner (30) found that correlation of nitrate leaching losses with rainfall is not as direct as might be expected. He hypothesized that the distance which nitrate will move downward depends not so much upon the total rainfall as upon the amount of rainfall which actually passes through the soil. In a comparison of two application methods of ammonium nitrate fertilizer, Nelson (58) observed that there was little movement of ammonium-nitrogen, but nitrate-nitrogen moved downward about 56 cm during the growing season.

Johnston et al. (40) found that large percentages of applied nitrogen were lost in tile drainage effluent from silty clay loam soils. He observed that most nitrogen lost was in the nitrate form, but some was in the form of NH_3, NO_2 and even organic nitrogen. In a study by Stewart et al. (80), more nitrate-nitrogen accumulated under irrigated fields than under dryland cropped conditions in eastern Colorado.

Olsen et al. (59) found that the total amount of nitrate-N in soil profiles was directly related to the rate of nitrogen applied. Other researchers have found that nitrate movement in the soil over time is not as great as would be expected.

Peterson and Attoe (65) found that on well-drained silt loam soils and with moderate rainfall, losses of nitrogen by leaching were small. They observed that most of the nitrate-nitrogen not removed by the crop was found in the soil within the root zone. Moore (55) found that nitrate-nitrogen movement through the soil was considerably slower than movement of the percolating water.

Larson et al. (45) observed an apparent lack of nitrate-N movement and accumulation in fine-textured soils under northern climatic conditions even under high rates of continuous nitrogen fertilization. Boswell and Anderson (13) found little movement of mineral nitrogen in a sandy clay loam and a loamy sand after 5 months. Even with high accumulated rainfall, appreciable amounts of the applied N were evident at 1-2 meter depths 18 months after nitrogen was applied to fallowed plots.

Data obtained by Herron et al. (34) shows that nitrates in large amounts accumulated during a three-year period in Nebraska, but it apparently stayed within the root zone even under irrigated conditions. Accumulation of nitrate-N below 180 cm has been found to be very slight in these soils.

Cornfield (25) found that nitrate-nitrogen accumulation in incubated soils was significantly correlated with total nitrogen and organic carbon contents. Pratt and associates (70) found that in order to ascertain nitrate-N concentrations in the unsaturated zone (the area below the root zone and above the water saturated zone), it is necessary to know (1) the volume of drainage water, (2) the yearly excess of nitrate available for leaching, and (3) an estimate for denitrification.

Since nearly two-thirds of the total annual precipitation occurs in the northern great plains region during the May-September period, leaching during winter months is usually not a problem in this area (34). The usual period when heavy rains are likely to occur and which might cause leaching of nitrates in soils would appear to be spring when cultivated crops are not yet established. Herron et al. (34) summarized that utilization of residual nitrate-nitrogen by plants would appear to be the best and most practical method for preventing build-up of nitrate in the soil profile. Olsen et al. (59) stated that the most effective methods for limiting the amounts of NO_3-N passing through the soil profile include: maintaining a crop cover on the land as much of the time as is feasible, reducing the acreage and frequency of crops that receive fertilizer-N in the rotation, and limiting the rate of N fertilization to approximately that required by the crop.

Nitrates can accumulate near the soil surface after extended dry periods (75, 77, 87). Simpson (75) argued that nitrate-nitrogen is microbiologically assimilated during progressive drying of the topsoil and is protected by the dry conditions from leaching or microbiological reduction. He hypothesized that transport of nitrate ions to the surface in the soil solution by capillary transport is not responsible for the major nitrate accumulation near the soil surface.

Stephens (77) also postulated that most accumulations of nitrate in the topsoil are probably due to the microbiological manufacture of nitrate during nitrification. During dry spells in Uganda, a limited amount of upward movement of soil solution can occur and this gave rise to some accumulation of nitrate in the surface soil.

Wetselaar (87) stated that accumulation of nitrate near the soil surface in Australia must be physical movement, because soil temperatures were too high and soil water content too low for biological nitrification processes to take place. He also rebuked photo-chemical oxidation reactions of nitrate formation because of shallow penetration of ultra-violet light and the adverse effect of the heat component of radiation on decreasing nitrate content in the surface soil.

Ammonium-Nitrogen Losses by Volatilization

When materials containing or yielding ammonium are applied to the soil in the irrigation water or by broadcast methods followed by irrigation, the greater portion of the ammonium is adsorbed at or near the soil surface (38, 39). The equilibrium reactions between the soil base-exchange compounds and the soil solution adjust so that ammonium compounds are present in the soil solution as long as ammonia exists in the adsorbed state (50). If the soil solution is alkaline, then a part of the ammonia will be present as hydrated ammonia, ammonium hydroxide, ammonium bicarbonate, and ammonium carbonate, depending on the alkalinity, concentration and other factors.

Ray et al. (71) found that migration of ammonium-nitrogen is closely related to the movement of water. The magnitude of migration is dependant upon such soil characteristic as texture, organic matter content, and CEC. There is less retention of ammonium-nitrogen in sandy soils and movement is predominantly downward and lateral. In finer textured soils, such as loams and silt loams, ammonium-N movement is more symmetrical with slightly greater upward and lateral movement than downward movement.

According to Allison et al. (3), subsoils can fix much more ammonium-nitrogen than surface soils. They also found that considerable moist fixation can occur in soil if the predominant clay mineral is illite or vermiculite, and these values are increased by drying and heating.

Nitrogen fertilizer losses as gaseous N compounds must be evaluated before the effects of continuous applications of nitrogen fertilizers on the soil can be accurately measured. Losses of fertilizer in irrigation or rain water run-off must also be determined. According to Moe et al. (54), applied ammonium nitrate fertilizer, because of its high ionization, is adsorbed and held near the soil surface. A more non-ionized N source, such as urea, is carried further down into the soil with the first increment of rainfall and therefore is less subject to surface run-off loss. Urea is rapidly hydrolyzed to ammonia in the soil and little loss as nitrate-N occurs. Moe further states that run-off losses of surface applied N fertilizers are greatest when the fertilizer is applied to very wet soils or to fallow soils having a surface seal.

There is widespread agreement among investigators that ammonia can be lost readily from the soil by volatilization (39, 48, 50, 86). Allison (4) states that ammonia volatilization losses from the soil, under suitable conditions, may amount to 25% or more of the ammonia added or formed. Kresge and Satchell (44) observed that no ammonia was volatilized from ammonium nitrate as long as the soil pH did not rise above neutral. Losses increased markedly at pH values above 7.0. Losses from alkaline soils containing much NH_3 near the surface increased as soils became dry. There were also high ammonia losses from soils with low CEC.

Jewitt (39) found that substantial quantities of N added in the form of ammonium sulfate to alkaline soils was lost. According to Martin and Chapman (50) evaporation of water was necessary for appreciable volatilization of ammonia from the soil to occur. Losses increased as temperatures became higher.

Meyer et al. (53) also observed that NH_3 losses were greatest when such fertilizers as urea, urea-ammonium nitrate solutions, ammonium sulfate, and ammonium nitrate were applied to neutral to alkaline soils under conditions of limited rainfall. Losses were magnified by the presence of crop residue on the soil surface and accentuated by cool temperatures which limited nitrification. Fuller (29) observed that volatilization losses from ammonium-containing fertilizers under aerobic conditions are greatly reduced by placing the fertilizers below the surface of the soil. He also stated that losses of volatilized ammonia formed by mineralization of organic compounds in the soil are rarely significant.

Yaalon (92) found that ammonia concentrations in monthly composite rain water samples collected in Israel showed marked dependence on soil temperatures, increasing significantly as soils warmed up in the spring. He attributed this to the release of pedogenic ammonia from calcareous soils at the beginning of the warm spring. Losses from ammonium-containing fertilizers were also considered a contributing factor.

According to Robinson (73), ammonification decreased when soil moisture level decreased below the permanent wilting point (PWP), but still took place quite actively at low soil moisture levels. Since nitrification was retarded at low moisture levels, there was a consequential build up of ammonium-N. After 8 days of incubation at $35^{o}C$, little nitrate-N was found in soil that was air dry prior to incubation, whereas nearly 10 ppm ammonium-N were found. At moisture levels below PWP, ammonium-N started to accumulate, while nitrate-N levels remained constant.

Nitrogen Losses Due to Denitrification

Bremner and Shaw (14) described denitrification as a biological process whereby nitrates are reduced to gaseous nitrogen compounds such as nitrous oxide and molecular N. They concluded that denitrification occurs only when the oxygen supply in the soil is restricted. Arnold (8) and Jones (41) support this viewpoint.

Wagner and Smith (85) determined that nitrous oxide (N_2O) may account for a large part of the nitrogen loss under denitrifying conditions. They reported up to 85% of the applied urea nitrogen was lost from a treatment in one study. They also noted that clay soils normally lose more nitrogen due to limited aeration that favors denitrification.

Allison (4), who has stated that nitrogen balance sheets often do not account for all the nitrogen originally present in or added to well-aerated soils, verified that soil nitrogen can be lost as nitric oxide, nitrous oxide, NH_3 and N_2. Soils which are approaching saturation with moisture rapidly release large amounts of their available nitrogen as nitrous oxide. At lower moisture contents, very slow evolution of the gas can take place (8).

Bremner and Shaw (14), Clark et al. (22), Meek et al. (52), and Patrick and Wyatt (63) all described conditions that enhance denitrification in the soil. The rate of denitrification increased with a rise in pH, temperature, and moisture content (14). The instability or reactivity of nitrous acid in soils is primarily responsible for the large volatile losses of N commonly observed during the course of the mineralization and nitrification processes in many well-aerated soils (22).

Broadbent (16), Broadbent and Stojanovic (17), and Jannson and Clark (37) all found that appreciable denitrification can occur under apparently aerobic conditions. Kefauver and Allison (43) observed nitrite reduction under aerobic conditions.

Work by Meek and MacKenzie (51) tended to eliminate the accumulation of nitrite as a factor causing large losses of gaseous nitrogen from alkaline soil under aerobic conditions. In another study (74) little N_2O was found under alkaline soil conditions, but N_2O production exceeded N_2

production under acid conditions. Fine textured soils showed a tendency to lose more N_2 than N_2O, and ammonium nitrate treatment favored evolution of nitrous oxide. Smith and Clark (76) found no loss of nitrogen as either nitric oxide or nitrogen dioxide from moist, aerobic soil. Nitrite can accumulate in soil as a lag phase in nitrification under alkaline conditions unfavorable to Nitrobacter spp. (56, 85).

Loewenstein et al. (48) showed that denitrification and nitrification in the soil proceeded simultaneously. They speculated that nitrates produced in the aerobic soil area moved to oxygen-poor regions and became subject to denitrification. Aerobic areas in the soil may have become anaerobic as a result of rapid oxygen consumption or because of concurrent CO_2 evolution by the soil microflora. Broadbent and Clark (18) have noted that the reduction of nitrite under aerobic conditions as a factor of denitrification may be of considerable importance, since nitrite may be formed in soils either from reduction of nitrates when oxygen is lacking or from oxidation of ammonium when oxygen is adequate.

Effects of Phosphorus Application on Soil Chemical Properties

Applications of phosphorus fertilizer over a continuous period of time also have been shown to have an effect on the chemical properties of soils. Several researchers have found that inorganic phosphorus is quite immobile in the soil and does not move far from the point of application (40, 68, 82). Soluble P rarely moves more than 2 or 3 cm from a fertilizer granule before reaction with soil components essentially stops further movement. Repeated applications will result in slow downward movement to 10-15 cm. This limited movement of P in the soil indicates the need for initially placing fertilizer P in the proper position for maximum effectiveness.

According to Taylor (82), essentially no phosphorus moves downward by water percolation because most fertilizer P is converted to water-insoluble forms rapidly after application to the soil. Phosphorus immobility is due to the elements' strong adsorption by finely divided mineral soil particles of the clay fraction (40, 82).

When soluble phosphate fertilizers are added to calcareous soils, they react with $CaCO_3$ through rapid monolayer sorption on $CaCO_3$ surfaces, and, at high phosphate concentrations in the vicinity of the fertilizer particles, the precipitation of dicalcium phosphate and tricalcium phosphate or even apatite-like compounds (24).

Phosphorus moves in a calcareous soil primarily in organic forms (33). Addition of a microbial energy source to the soil increases the movement of organic P significantly, but no increase in the movement of inorganic phosphorus is obtained. Higher plants are unable to utilize the organic phosphorus found in the soil solution (33).

Bingham and Garber (11) found that on alkaline soils heavy phosphorus applications of 1,000 kg/ha resulted in acute copper deficiency, but both copper and zinc solubilities were increased by excessive P fertilization. These heavy treatments reduced the availability of molybdenum in alkaline soils. Zinc uptake was the same regardless of level of phosphorus treatment, whereas manganese, iron, and boron availability was increased with the heavy P treatment.

Effects of Fertilizer on Zinc Availability in Calcareous Soils

Most zinc disorders in plants occur in calcareous soils. Residually acidifying fertilizers applied to calcareous soils have been shown to increase the availability of several micronutrients (11, 84). Zinc availability is often a problem on calcareous soils, owing to the ability of calcium carbonate to transform zinc to sparingly soluble compounds (57). Zinc may be fixed at the surface of $CaCO_3$ particles. The greater the level of $CaCO_3$ of the clay fraction (carbonate clay) the less available the soil zinc. Jurinak and Bauer (42) also described this unavailability of zinc in calcareous soils as being due to zinc adsorption by carbonates or precipitation of zinc hydroxide or carbonate. Some soils retain Zn^{2+} as strongly as zinc silicate, and more strongly than zinc hydroxide or carbonate (83).

METHODS AND MATERIALS

The study consisted of a randomized complete block design with 5 replications of 36 treatments. Only 3 replications of 12 treatments were sampled since previous corn yields indicated no significant response to applied potassium or to an additional application of 19 kg/ha of P to half of each plot (Table 1).

The experimental area was located east of Tribune in Greeley county on the Experiment Station's irrigation site. The soil of the experimental area is a Richfield silt loam, which is a fine, montmorillonitic, mesic Typic Argiustoll. It is a deep, well-drained, nearly level (0-1% slope) soil of the uplands, developed from calcareous loess. The Richfield soil has a dark grayish-brown silt loam surface layer over grayish-brown silty clay loam subsoil, which grades to lighter colored, very friable calcareous silty clay loam at 10-18 inches. Previous soil analysis data from the experimental site are indicated in Table 2.

Soil Sampling. The first replication was sampled on January 23, 1972, and the other two replications were sampled on February 20-21. Soil core samples were taken with a truck-mounted hydraulic soil probe (Figure 1). Soil core samples were taken with a 5 cm diameter, 1.2 m slotted stainless steel sampling tube. The sampling tube was inserted into the soil to a depth of approximately 1 meter and removed with an intact soil core inside. The sampling tube was removed from the drive head and placed on a channel board with a meter stick mounted on one side of the channel. The intact soil core was removed from the sampling tube with a wooden dowel and placed in the channel board for sectioning (Figure 2). The soil core was cut into 5 cm increments for the first meter. The coring process was

Table 1. Effects of nitrogen, phosphorus, and potassium on the yield[1] of irrigated corn.

Treatment N	P	K	1961	1964	1967	1970		1973		1968-73 avg.		1961-73 avg.
kg/ha												
0	0	0	2,509	3,450	2,697	5,080	5,457[2]	3,199	4,328[2]	4,140	4,328[2]	3,575
45	0	0	5,645	5,268	5,394	8,530	8,467	7,276	6,962	6,962	6,962	6,147
90	0	0	7,726	7,715	7,401	9,722	10,537	8,467	8,718	8,028	8,718	7,715
134	0	0	7,338	8,091	7,903	9,533	11,227	8,781	9,659	8,028	9,659	7,965
179	0	0	8,404	8,279	8,404	10,537	12,356	8,718	10,349	8,593	10,349	8,593
224	0	0	7,903	8,216	8,844	10,600	12,105	9,847	10,286	8,781	10,286	8,655
0	19	0	2,572	3,450	3,324	5,268	5,457	3,450	4,328	4,265	4,328	3,700
45	19	0	5,143	5,645	6,084	9,094	8,906	7,087	7,401	7,401	7,401	6,523
90	19	0	7,150	7,401	8,154	10,474	10,349	9,471	9,032	9,032	9,032	8,216
134	19	0	7,715	8,216	9,533	11,854	11,227	11,101	10,098	10,035	10,098	9,283
179	19	0	8,154	8,279	9,408	11,917	12,230	11,854	10,537	10,600	10,537	9,659
224	19	0	8,404	8,844	9,408	12,168	12,544	11,478	10,725	10,537	10,725	9,722
0	19	37	2,634	3,261	3,199	5,457	5,206	3,324	4,265	4,265	4,265	3,763
45	19	37	5,331	5,331	5,896	9,345	8,906	7,589	7,025	7,401	7,025	6,397
90	19	37	7,025	7,213	8,028	10,286	10,412	8,781	8,844	8,718	8,844	8,091
134	19	37	8,154	8,342	8,906	11,540	11,854	10,913	10,161	9,910	10,161	9,220
179	19	37	8,028	8,844	9,471	12,293	12,230	11,478	10,788	10,537	10,788	9,722
224	19	37	8,028	9,157	9,533	12,357	12,293	11,540	10,662	10,662	10,662	9,784

1/ Corrected to 12.5% moisture, kg/ha
2/ 19 kg/ha phosphorus were added to half the plots

Table 2. General soil analysis date from the experimental area prior to the current investigation.

(Composite samples)

		Organic Matter %	pH	Avail. P pp2m	Exch. K pp2m
Corn:	1961	1.4	7.9	34	550+
Nov.,	1964 N only	1.5	7.8	13	550+
	N + P	1.4	7.8	30	550+
Nov.,	1967 N only	1.4	7.9	11	550+
	N + P	1.5	7.9	37	550+
Dec.,	1970 N only	1.7	7.7	16	550+
	N + P	1.7	7.7	32	550+

repeated until a composite core of 4 meters had been collected. The lower 3 meters were sectioned into 20 cm increments. Two cores were collected from each plot and combined into a single composite sample. Samples were placed in soil sample bags for transportation to the laboratory. Since two 20 cm increments from the duplicate cores (5 cm diameter) would not fit into a sample bag, it was necessary to split these sections along the vertical axis and retain half of each section.

Samples from the first sampling date were returned to the laboratory and placed directly in a forced air oven and dried at 55°C for 4 days. The dried soil samples were then ground with a hammer mill, screened through a 14-mesh screen, mixed and stored in sealed glass bottles. The samples from the second sampling date were frozen for approximately 1 month before being dried and ground.

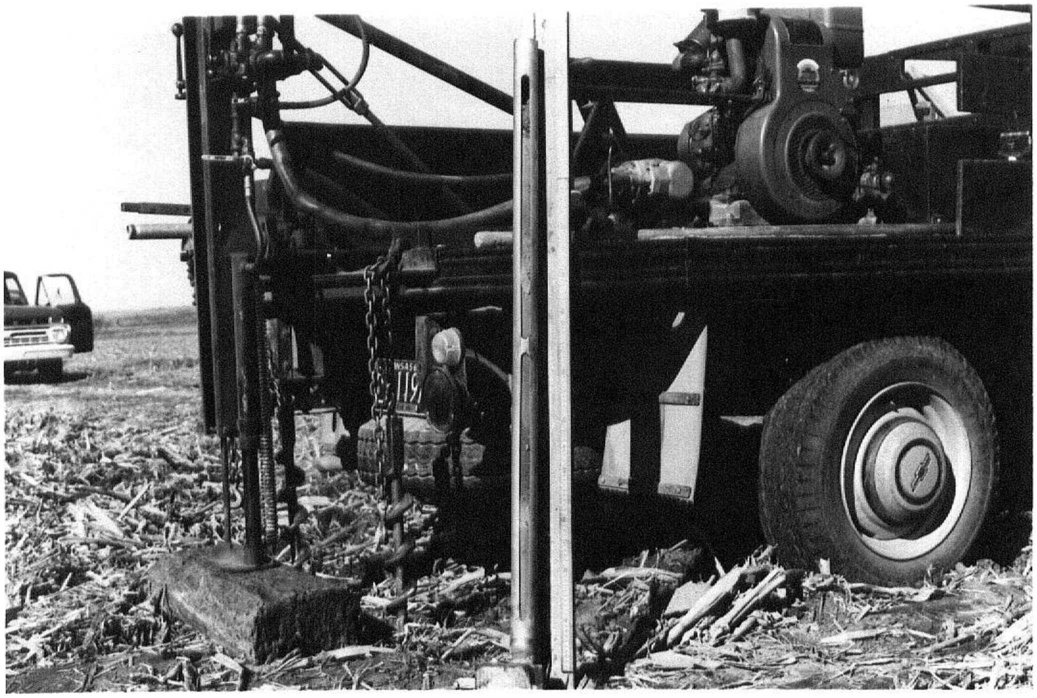

Fig. 1. Truck-mounted hydraulic soil probe used to obtain soil core samples.

Fig. 2. Method used for sectioning soil cores into desired increments.

The soil samples were analyzed for NH_4^+-N, NO_3-N, total N, pH, available P, extractable Ca, Mg, Na and K, CEC, extractable Cu, Fe, Mn and Zn, total C, CO_3^{2-}-C and organic C.

Ammonium and Nitrate Determinations. A steam distillation procedure outlined by Bremner and Keeney (15) was used for NH_4^+-N and NO_3^--N determinations. A 4 g portion of each sample was weighed and placed in a 300 ml distillation flask along with 20 ml of 2M KCl and 0.2 g of MgO. This mixture was steam distilled and 25 ml of distillate were collected in a 5 ml aliquot of 2.0 percent boric acid-mixed indicator solution.[1] The 30 ml mixture of indicator solution and distillate were then titrated with standard 0.00557 N sulfuric acid from a 5 ml microburet graduated at 0.01 ml intervals. Blanks of deionized water were used to correct all samples. Results were calculated in ppm NH_4^+-N.

Nitrate-nitrogen was determined on the same soil sample following ammonium-nitrogen determination by adding 0.2 g of ball-milled Devarda's alloy to the distilling flask and immediately distilling another 25 ml of distillate into 5 ml of H_3BO_3-mixed indicator solution. The sample was titrated with the standard sulfuric acid and the results calculated in ppm NO_3^--N.

Total Nitrogen. Total soil nitrogen, excluding NO_3^--N, was determined on a 1 g soil sample by the macro-Kjeldahl procedure described by Jackson (36).

---

[1]Indicator solution consisted of 20 g H_3BO_3 and 20 ml of mixed indicator dissolved in 700 ml of warm water and brought to a 1 l volume; adjusted with 0.05 N NaOH until 1 ml of mixed indicator solution added to 1 ml of distilled deionized H_2O gave a bluish-green color. Mixed indicator solution made up by dissolving 0.99 g of bromocresol green and 0.66 g of methyl red in 1 l of absolute ethanol.

pH. Soil pH was determined by adding 5 ml of distilled water to 5 g of soil, stirring the mixture, and measuring the pH after 20 minutes by standard potentiometric methods.

Available Phosphorus. Phosphorus was determined as weak acid extractable P using the Bray-1 extracting solution with subsequent colorimetric determination. The extractant used was 0.03 N NH_4F and 0.025 N HCl. The color development of the extracted solution was by reduction of the solution with 1-amino-2-napthol-4-sulfonic acid to allow formation of a phospho-molybdate-complex.

Extractable Cations. Extractable Ca, Mg, Na, and K were determined by using a centrifuge extraction procedure with 0.1 N ammonium acetate as described in Jackson (36). A correction procedure for the solubility of Ca and Mg carbonates in the leachates was also used. The supernatant was evaporated to dryness on a hot plate, then dissolved and brought up to volume in 0.1 N HCl. Calcium and magnesium were determined by the use of a Perkin Elmer model 303 atomic absorption spectrophotomer. Flame photometry was used for determination of Na and K.

Cation Exchange Capacity. Cation exchange capacities were determined by washing the soil sample from the extractable cations procedure with methanol until all excess ammonium acetate was removed. The sample was transferred to a 800 ml Kjeldahl flask with 300 ml deionized water, 10 ml of 50% NaOH and mossy zinc. Ammonia was distilled and the distillate collected in 30 ml of boric acid-methyl purple indicator until 150 ml of distillate were collected. The 175 ml mixture of indicator solution and distillate were then titrated with standard 0.0714 N H_2SO_4. Cation exchange capacities were calculated and expressed as meq/100 g soil.

Micronutrients. Extractable Cu, Fe, Mn, and Zn were determined by using the DTPA-TEA extraction procedure (20, 47). Ten grams of soil were placed in a centrifuge tube and 20 ml of DTPA extracting solution were added. The tubes were covered with plastic stoppers and shaken on a wrist-action shaker for 2 hours. The samples were then centrifuged for 3 minutes and filtered into polyethylene bottles. Extractable Cu, Fe, Mn and Zn were determined by atomic absorption spectrophotometry.

Carbon. Total carbon was determined on samples from 4 treatments by the use of a Leco carbon analyzer through the courtesy of the Department of Crop and Soil Sciences, Michigan State University (6, 10, 81). One hundred milligrams of finely ground soil (80 mesh) were weighed into a special ceramic crucible and one scoop (approximately 1 gram) each of iron chips and tin accelerators were added. The crucible was then placed in a combustion tube of an induction furnace through which O_2 was being passed. The sample was combusted at a temperature of over 1670^{o}C with the carbon in the sample being oxidized to CO_2. The gas mixture was passed through (1) a dust trap to filter out the solid tin and iron oxides, (2) a sulfur trap containing MnO_2 to absorb sulfur gases which may have been oxidized during the combustion of the sample, and (3) a heated catalyst to convert any CO formed to CO_2. Moisture was removed from the gas mixture before it entered the analyzer by an anhydrone trap. After combustion and passing through the purification train, the gas mixture was passed into a cylinder housed in a temperature-controlled oven (45^{o}C) in the analyzer. The thermal conductivity of the mixture in the cylinder was measured by a thermistor-type thermal conductivity cell. The output of the thermal conductivity cell was read on a special DC digital voltmeter as percent carbon.

Carbonate-carbon was determined using the acid-neutralization method outlined in Black (7). Five grams of soil were placed in a 150 ml beaker and 50 ml of 0.544 N standarized HCl were added. The beaker was then covered with a watchglass, placed on a hot plate, and boiled gently for 5 minutes at 150°C. After cooling, the contents were filtered and washed with 50 ml of deionized water. Five drops of phenolphthalein indicator were added to the filtrate and it was titrated to the endpoint with 0.251 N standardized NaOH. Carbonate-carbon was then calculated and expressed as percent carbonate-carbon.

Approximate organic carbon percentage for each sample analyzed for total carbon was determined by subtracting percent carbonate-carbon from percent total carbon (5).

Statistical analysis was completed on the data using the least squares method. All results were reported at the 5% level of significance.

RESULTS AND DISCUSSION

Detailed soil anaylsis results are presented in appendix tables 1-47. Tables in the text of this chapter showing mean values are averaged across nitrogen rates, phosphorus rates, or depth, whichever is appropriate concerning the specific treatment or depth effect demonstrated.

Ammonium-nitrogen

Ammonium-nitrogen accumulations in the soil of the experimental area were exceptionally high, especially in samples collected at the later sampling date. Some samples had ammonium-nitrogen concentrations that exceeded 200 ppm. There was a trend for ammonium-N concentration to increase with added nitrogen, but this was not significant at the 0.05 level of significance (Table 3). Ammonium-nitrogen was significantly higher where 19 kg/ha applications of phosphorus had been used. There was a significant decrease in ammonium-N with depth as shown in Figure 3. Little downward movement of ammonium-N occurs since it is tightly adsorbed by the soil colloids and is not susceptible to leaching. However, appreciable concentrations of ammonium-nitrogen were present even at depths of 400 cm (Table 4).

The high concentrations of ammonium-N indicated possible contamination by atmospheric refrigerant ammonia during cold storage. This source of contamination would only have affected samples collected at the later date, since the first set of soil samples were not frozen before being dried. Since adsorption of NH_4^+ and other cations is related to soil CEC, this particular soil would be expected to have fairly uniform ammonium-N concentrations throughout the profile if contamination was a problem, since CEC did not vary appreciably with depth. Lack of significant variation of CEC with depth raises some question concerning ammonia contamination.

Table 3. Mean values for ammonium-N, nitrate-N, total N, pH, and available P as affected by N rate or P application.

Treatment kg/ha	ammonium-N ppm	nitrate-N ppm	total N ppm	pH	avail. P ppm
0 N	50.90	2.62	737	8.17	8.53
45 N	52.74	2.23	752	8.12	8.54
90 N	54.98	2.72	728	8.14	7.98
134 N	55.15	4.02	751	8.13	5.52
179 N	57.35	4.55	737	8.12	6.55
224 N	56.78	6.96	749	8.11	5.75
$LSD_{.05}$	NS	0.45	NS	0.01	1.24
0 P	51.18	3.66	751	8.14	4.68
19 P	58.13	4.04	733	8.12	9.62
$LSD_{.05}$	2.75	0.26	15	0.01	0.71

Environmental and soil conditions at time of sampling may have been conducive for mineralization of soil N without subsequent formation of nitrate-nitrogen through the nitrification process. Reduced aeration, cold temperatures, and high soil pH all adversely affect nitrification to a greater extent than ammonification.

Since mineralization proceeds most rapidly in well-aerated, warm soils with plenty of basic cations present, this process may have been stimulated while the moist samples were being dried prior to preparation for analysis. Ammonification has been shown to take place at very low soil moisture contents, and at fairly high temperatures (50-70°C). Therefore, ammonification could have been occuring without subsequent nitrification before the soil became too dry, resulting in ammonium-N accumulation.

The increased ammonium-N concentrations accompanying added phosphorus indicate that this increased availability of P may have been utilized by heterotrophic soil organisms to stimulate mineralization of organic nitrogen compounds and increased production of ammonium-N.

Table 4. Mean values for ammonium-N, nitrate-N, total N, pH, and available P as affected by depth.

Depth, cm	ammonium-N	nitrate-N	total N	pH	avail. P
	ppm	ppm	ppm		ppm
0-5	108.27	9.22	1258	8.01	16.11
5-10	117.20	13.48	1180	7.98	13.10
10-15	110.92	11.52	1141	7.93	8.01
15-20	103.70	7.99	1161	7.93	7.13
20-25	111.37	5.59	1116	7.98	5.72
25-30	106.07	4.17	1052	8.01	3.73
30-35	99.11	3.01	963	8.08	2.22
35-40	91.20	3.11	899	8.08	1.16
40-45	84.57	2.94	844	8.10	
45-50	81.04	3.04	797	8.11	
50-55	73.60	3.23	772	8.13	
55-60	68.03	3.15	748	8.14	
60-65	61.91	2.84	696	8.15	
65-70	57.53	3.13	689	8.16	
70-75	54.51	3.15	694	8.16	
75-80	55.28	2.84	709	8.18	
80-85	51.77	2.75	703	8.17	
85-90	48.62	2.90	672	8.18	
90-95	48.18	2.65	679	8.18	
95-100	44.79	2.84	695	8.18	
100-120	34.77	2.23	575	8.18	
120-140	30.96	2.43	566	8.18	
140-160	27.21	2.56	564	8.18	
160-180	22.37	2.60	541	8.19	
180-200	19.96	2.72	533	8.16	
200-220	20.21	2.72	531	8.16	
220-240	18.60	2.77	510	8.17	
240-260	22.16	3.18	546	8.16	
260-280	20.10	3.06	558	8.17	
280-300	20.73	3.43	586	8.16	
300-320	21.12	2.92	609	8.17	
320-340	19.34	2.92	570	8.19	
340-360	20.24	2.73	624	8.22	
360-380	19.05	2.43	591	8.24	
380-400	18.30	2.49	607	8.25	
$LSD_{.05}$	11.50	1.08	64	0.03	1.43

Some fixed ammonium-N could have been released from the soil organic matter fraction during steam distillation if it were somewhat water soluble. Physically sorbed ammonia also could have been released during the steam distillation procedure. This soil probably had high ammonium-N fixing capacity, since expanding clay minerals like montmorillonite have large adsorption capabilities. Ammonium-N fixation by the organic fraction of mineral soils increases with pH. Clays saturated with divalent ions also generally have higher ammonium contents than clay saturated with monovalent ions.

Nitrate-nitrogen

Soil nitrate-nitrogen concentrations were much lower than ammonium-nitrogen levels. Individual sample values ranged from none to 27 ppm. Nitrate-nitrogen decreased with depth as shown in Figure 4, and both nitrogen and phosphorus treatments had a significant effect on the accumulation of nitrate-nitrogen (Table 3). The pattern of accumulation indicates nitrates are moving downward uniformly, as there are no large peaks of nitrate accumulation in the soil profile. There is an observable increase in nitrate-N at the 300 cm depth, and then concentration decreases again (Table 4).

The increased accumulation of nitrate-nitrogen with applied N indicates that at the high rates some nitrogen fertilizer is not being utilized by the corn crop. The effect of P on nitrate-nitrogen may be secondary in that phosphorus has a beneficial effect on soil organisms that enzymatically hydrolyze organic nitrogenous compounds and proteins and subsequently manufacture ammonia which is oxidized to nitrate-nitrogen. If this is the case, then total soil nitrogen and organic carbon, which are the main constituents of organic matter, should decrease with added P. Subsequent data show that this is so.

The effect of phosphorus on nitrate-nitrogen was most prevalent at the low nitrogen rates. The results of available nitrogen analyses indicate that more research is needed on this calcareous soil in regard to immobilization, mineralization, nitrification, and denitrification of soil nitrogen.

Total Nitrogen

Total soil nitrogen, excluding nitrate-nitrogen, decreased dramatically with depth, as illustrated in Figure 5. Concentrations were lowest at the 200-240 cm depth. Nitrogen had no effect on total N (Table 3), while phosphorus decreased the amounts of total nitrogen in the soil at all but the two highest nitrogen rates. This trend was probably explained by the fact that at low N rates, added phosphorus stimulated grain formation in preference to forage production, so that less organic nitrogen was returned to the soil as crop residue after grain removal. As nitrogen fertilization rates increase, grain yields reach a plateau and more phosphorus, as well as other plant nutrients, are incorporated into vegetative material which is returned to the soil following harvest. Total nitrogen content ranged from 130-1680 ppm in individual samples.

pH

The effects of nitrogen and phosphorus fertilizers on soil pH, though small, were significant as shown in Table 3. The effect of the nitrogen fertilizer on decreasing pH can be explained by the residually-acidifying effect of ammonium nitrate. The higher the N rate, the greater the potential acidity. Phosphorus applications at the lower nitrogen rates (0, 45, 90, and 134 kg/ha) decreased soil pH, but had no effect when applied with heavy nitrogen treatments. There was a significant increase in pH with depth, as shown in Figure 6, which implies that surface pH changes have not extended into the lower part of the soil profile. The large amounts of calcium carbonate in this soil indicate that no detrimental decreases in pH can be expected at the present fertilization rates. In fact, a decrease in pH would probably be beneficial as most micronutrients are more readily available at pH levels lower than those present in this soil. Soil pH varied from as low as 7.8 near the surface up to 8.4 at the 400 cm depth.

Available Phosphorus

Weak Bray extractable phosphorus content in the surface 5 cm was quite variable, ranging from 6 ppm with no applied P up to 37 ppm with 19 kg/ha of applied phosphorus as triple-superphosphate. Available phosphorus decreased as nitrogen rates increased. Added nitrogen probably stimulated P uptake by increasing crop growth. Much more available P was present with the P treatment as compared to plots that received no phosphorus fertilizer, as was expected. At low N rates, added P increased soil available P to a much greater extent than at higher N rates, indicating that nitrogen is limiting growth and P uptake at these low nitrogen rates. At higher nitrogen rates, phosphorus levels indicate that it is the limiting nutrient as shown in Figure 7. There was a marked decrease in available phosphorus with depth (Table 4). As phosphorus is relatively immobile, little downward movement of applied P would be expected. Previous data from this study indicate that available phosphorus did not tend to increase with time when 19 kg/ha was added but that the level in the soil remained at a fairly constant, adequate level. When no phosphorus was added, there was a trend for soil phosphorus to decrease with time (Table 2).

Extractable Calcium

Nitrogen applications had a significant effect on soil extractable calcium as shown in Table 5. There was a decrease in calcium with added N when no phosphorus was applied. With applications of nitrogen and phosphorus, no meaningful trends were apparent. Figure 8 indicates the effect of depth on calcium content. The area of lowest concentration (0-20 cm) is probably due to uptake and removal by crops and to loss of part of the calcium pool in the form of $CaCO_3$ through acidifying effects of organic acids and applied ammonium nitrate. Some calcium also probably leached downward and is

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

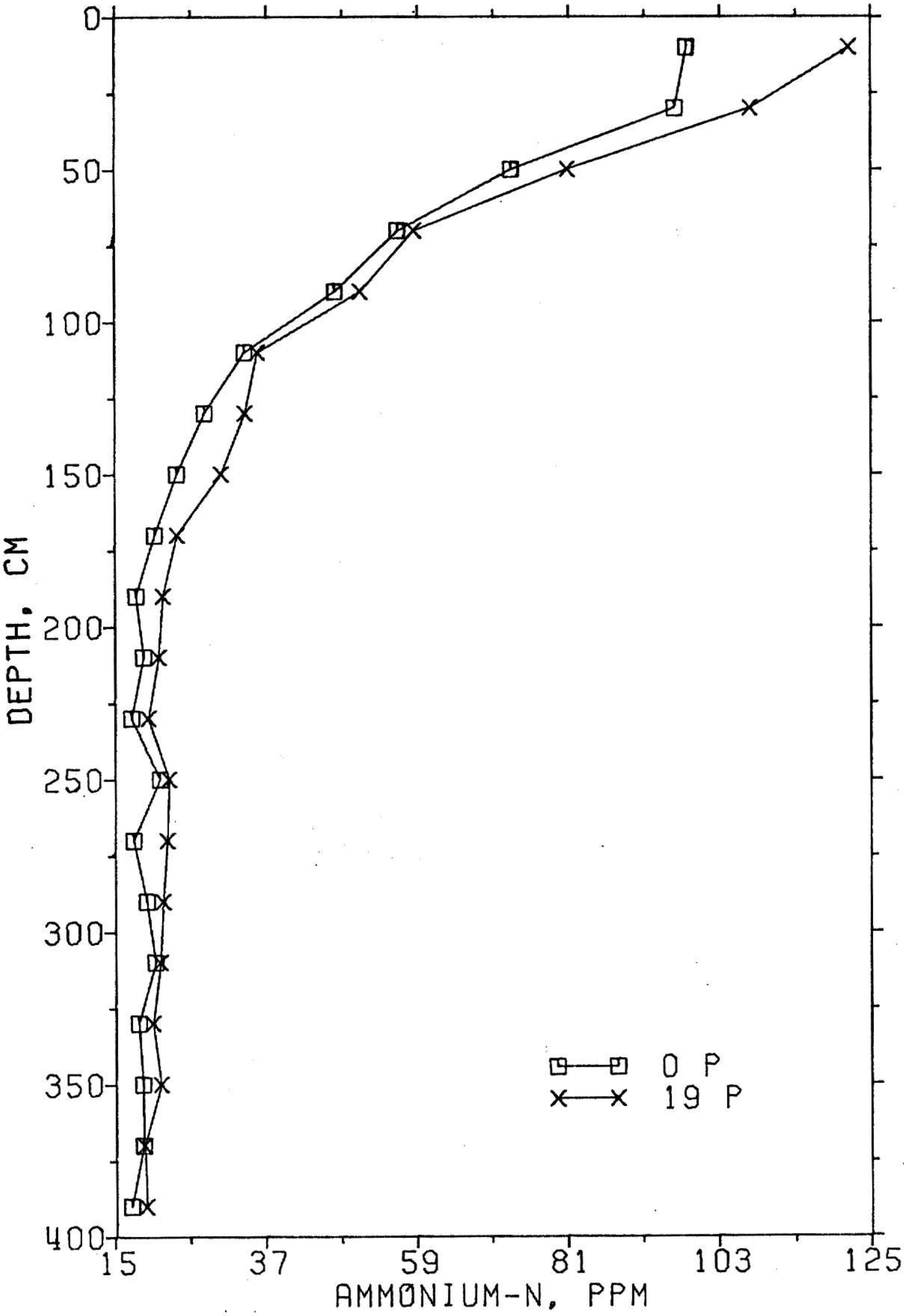

Fig. 3. Soil ammonium-N as affected by nitrogen and phosphorus treatments.

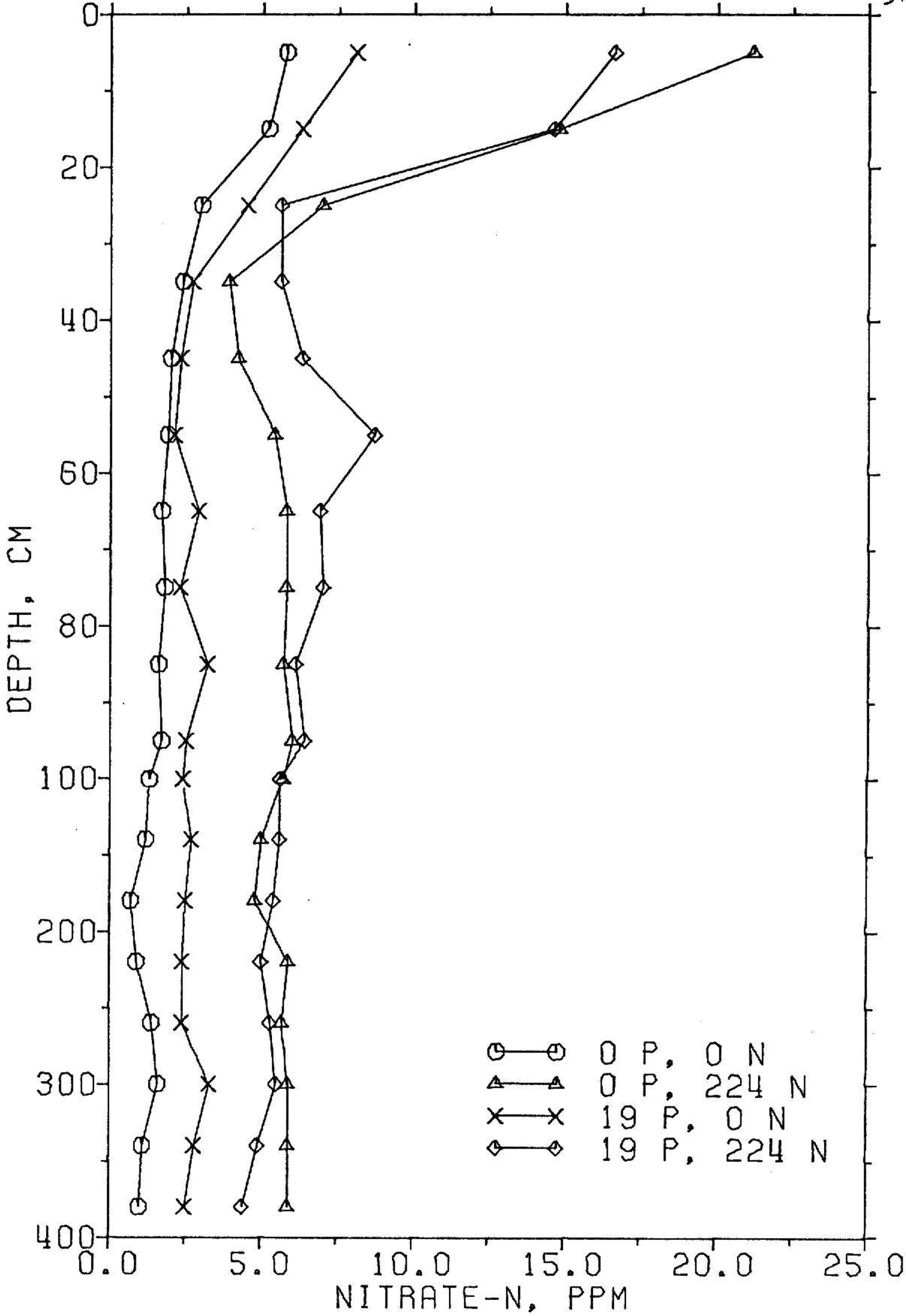

Fig. 4. Soil nitrate-N as affected by nitrogen and phosphorus treatments.

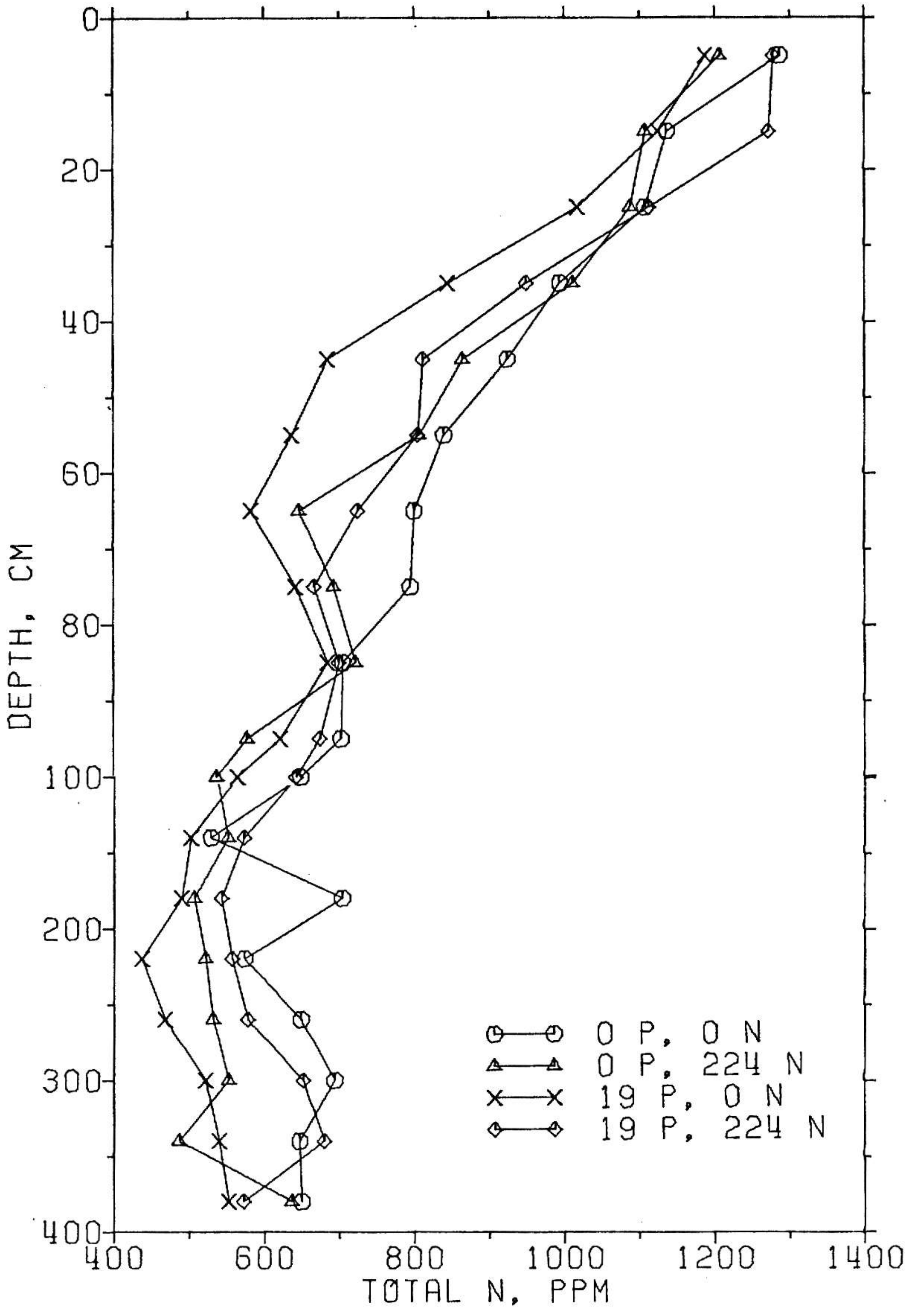

Fig. 5. Total soil nitrogen as affected by nitrogen and phosphorus treatments.

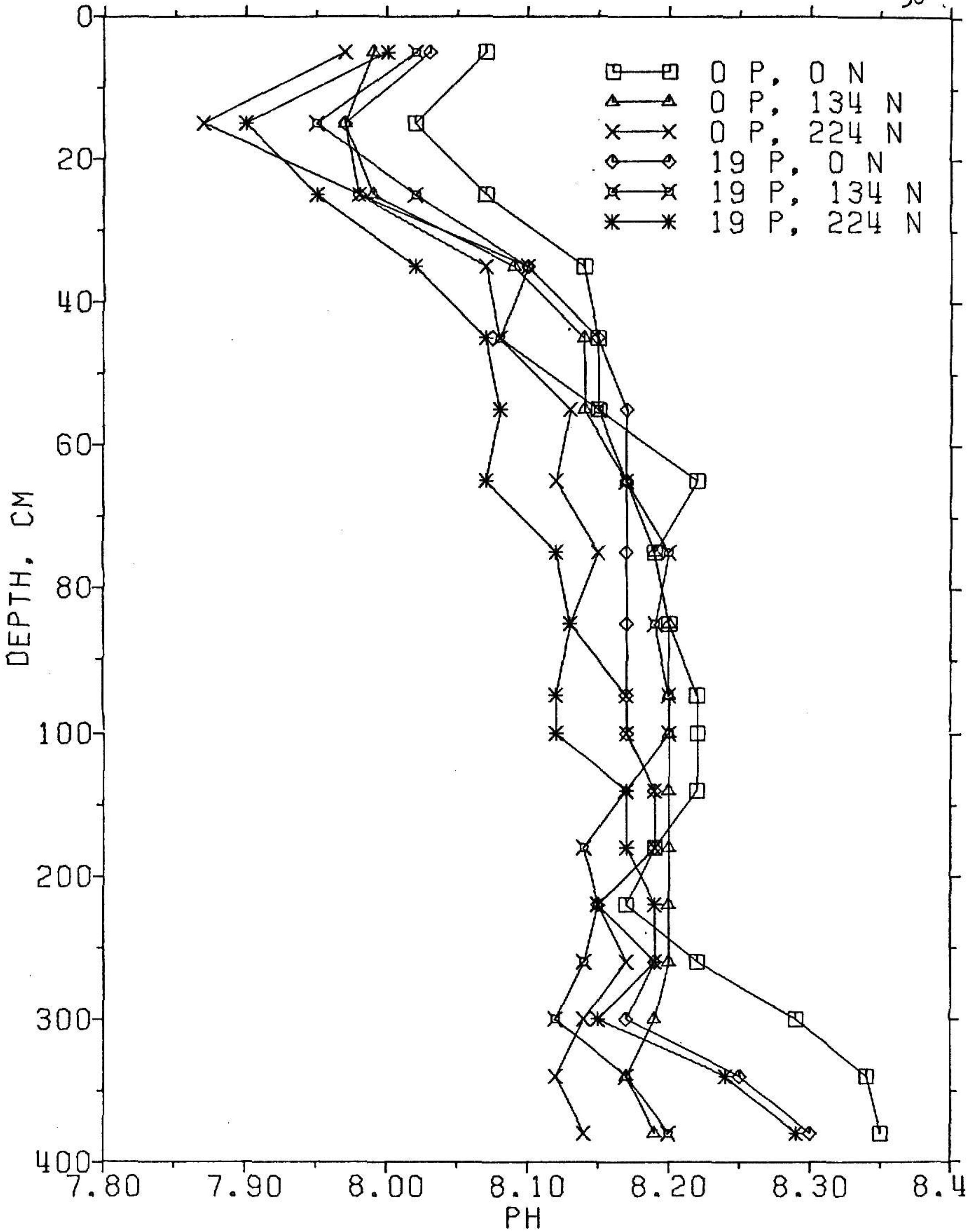

Fig. 6. Soil pH values as affected by nitrogen and phosphorus treatments.

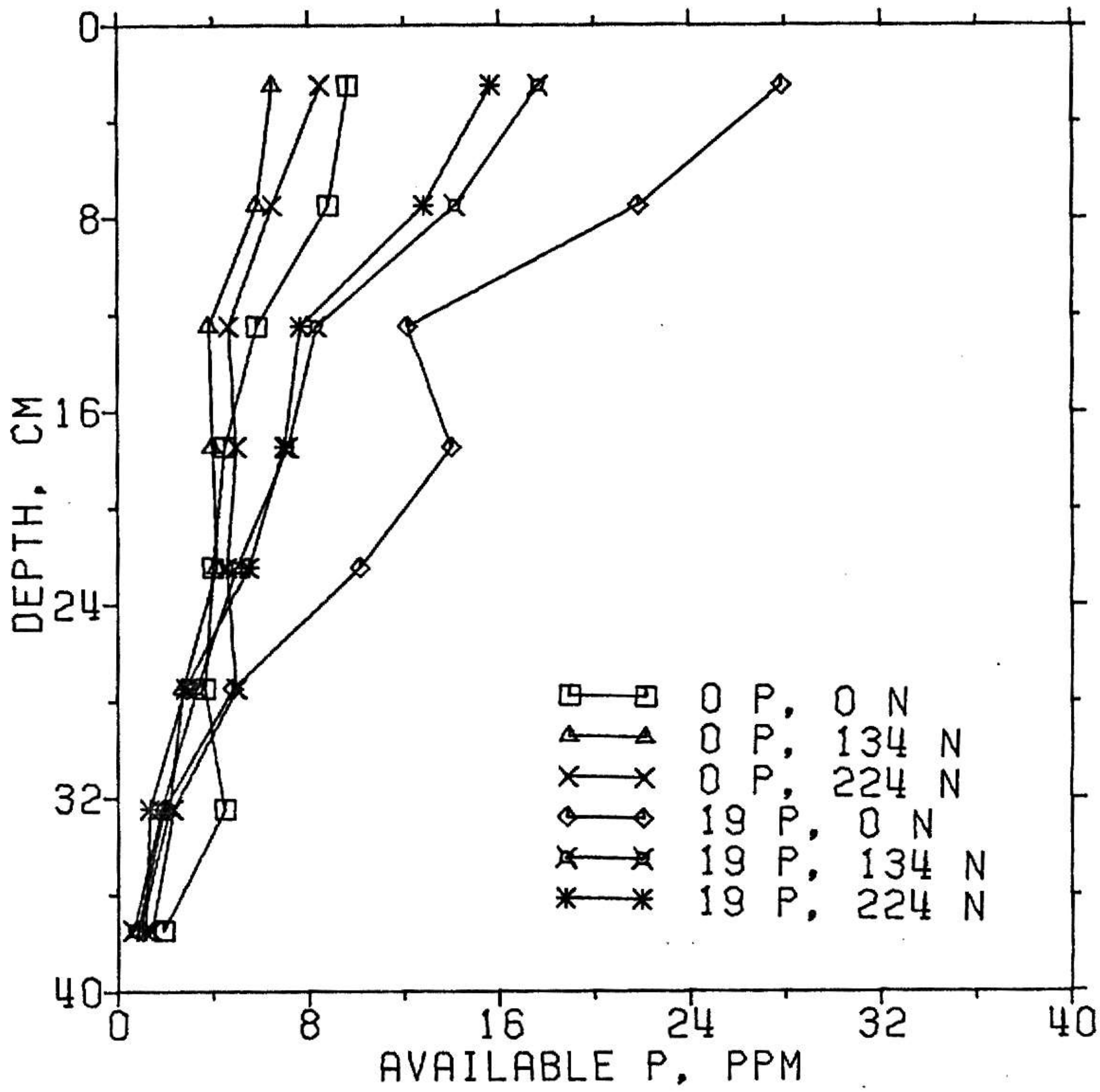

Fig. 7. Weak Bray extractable P as affected by nitrogen and phosphorus treatments.

Table 5. Mean values for calcium, magnesium, sodium, potassium, and CEC as affected by N rate, P application, or soil depth.

Treatment kg/ha	calcium ppm	magnesium ppm	sodium ppm	potassium ppm	CEC meq/100 g
0 N	15341	736	88.7	570	22.05
134 N	16039	711	83.3	557	21.75
224 N	14711	672	95.4	517	22.17
$LSD_{.05}$	912	16	7.3	17	0.19
0 P	15106	705	92.9	540	22.05
19 P	15621	708	85.4	556	21.93
$LSD_{.05}$	NS	NS	6.0	14	NS
Depth, cm					
0-5	8755	539	84.9	594	23.22
5-10	8749	526	91.4	563	23.30
10-15	8698	519	79.1	525	23.60
15-20	8865	509	66.0	510	23.27
20-25	11706	565	81.3	506	23.56
25-30	15836	624	84.3	485	23.67
30-35	17883	660	92.1	464	22.83
35-40	17834	649	90.6	435	22.12
40-45	16594	652	99.9	428	21.48
45-50	15424	685	99.1	437	21.23
50-55	16459	712	91.4	447	21.25
55-60	17855	753	92.5	475	21.08
60-65	18495	788	93.9	507	21.12
65-70	18583	806	95.6	553	21.15
70-75	17916	825	93.2	573	21.06
75-80	17905	854	86.4	622	21.28
80-85	17854	857	85.2	655	21.03
85-90	17286	860	94.2	684	21.01
90-95	17525	877	90.1	734	21.25
95-100	17045	867	91.8	764	21.26
$LSD_{.05}$	2354	41	NS	44	0.49

responsible for the zone of increased extractable calcium accumulation at the 60-70 cm depth. A correction procedure for free calcium and magnesium carbonates was used but extractable calcium concentrations still exceeded 20,000 ppm lower in the profile. The pattern for extractable calcium concentration is similar to that for carbonate carbon, indicating the close relationship between these two ions in this calcareous soil.

Extractable Magnesium

There was a significant decrease in soil extractable magnesium with applied nitrogen as shown in Table 5. This was possibly due to removal by the growing crops and to some downward leaching of soluble $MgCO_3$ though no zone of accumulation was apparent (Figure 9). Magnesium concentration increased with depth. Phosphorus application had no effect on soil extractable magnesium. Magnesium concentrations ranged from 450-900 ppm.

Extractable Sodium

Extractable sodium was significantly affected by both nitrogen and phosphorus fertilization. When 19 kg/ha of phosphorus was added, sodium content increased as N rates increased as shown in Figure 10. At the 0-N rate, the addition of phosphorus led to a decrease in extractable sodium content. Depth had no effect on sodium, indicating that plant uptake of this element is low and that it is associated with the mineral fraction of the soil and not the organic fraction. Sodium concentration in the soil was erratic and showed no pattern (Table 5).

Extractable Potassium

Extractable soil potassium was affected by nitrogen, phosphorus, and depth (Table 5). Potassium concentrations decreased with applied nitrogen, indicating increased plant uptake as yields increased. Extractable soil potassium increased when phosphorus was applied. This may have been due to the slight decrease in pH due to applied phosphorus. The decrease in alkalinity may have increased the availability of soil K. The addition of phosphorus also tended to increase soil extractable calcium, though the increase was non-significant (0.05). Since Ca^{++} tends to replace K^{+} on the soil exchange complex, this increase in extractable Ca^{++} would therefore result in an increase in extractable potassium.

The general decrease in extractable K at the 30-60 cm depth is likely due to uptake by plant roots. Since much potassium is found in the vegetative portions of corn plants, considerable amounts of plant K are returned to the soil upon incorporation of plant residues. This explains the accumulation of extractable potassium near the soil surface as shown in Figure 11. Corn yield data (Table 1) show that the addition of 37 kg K/ha does not influence any significant increase in grain yield. However, there is a slight increase at the two highest N rates when comparing the N + P treatments with the N + P + K treatments. This observation, in conjunction with the significant decrease in extractable potassium with increased N applications, implies that continuous heavy applications of N and P may ultimately result in the necessity to apply fertilizer K in the future. The grand mean for extractable soil potassium was 548 ppm.

Cation Exchange Capacity

Soil cation exchange capacity was affected by nitrogen treatment, but no obvious trend was apparent (Table 5). Phosphorus tended to decrease the soil CEC, but the effect was insignificant at the 0.05 level. There was a definite decrease in CEC with depth, which was due to less organic matter below the surface 25 cm as shown in Figure 12. Soil cation exchange capacity varied from approximately 20 meq/100 g to 25 meq/100g soil.

Extractable Copper

Soil DTPA-extractable copper was not significantly affected by either nitrogen or phosphorus treatment as shown in Table 6. There was a trend for soil copper to decrease with added phosphorus at the two lower nitrogen rates. Regardless of phosphorus treatment, DTPA-extractable copper was highest when 134 kg N was applied. Perhaps additional nitrogen increased extractability but at the highest nitrogen rate higher crop uptake may have reduced the

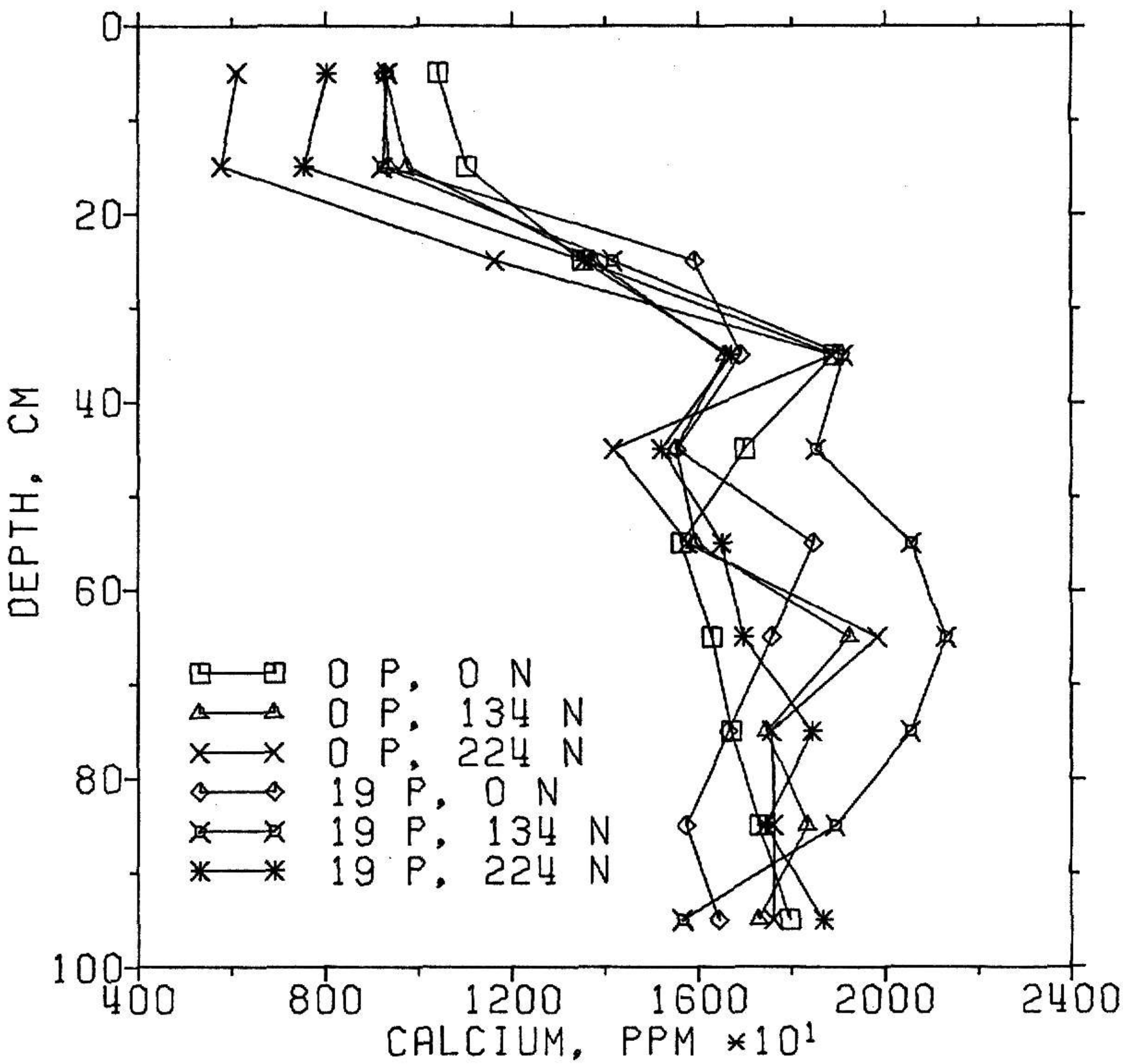

Fig. 8. Extractable soil calcium as affected by nitrogen and phosphorus treatments.

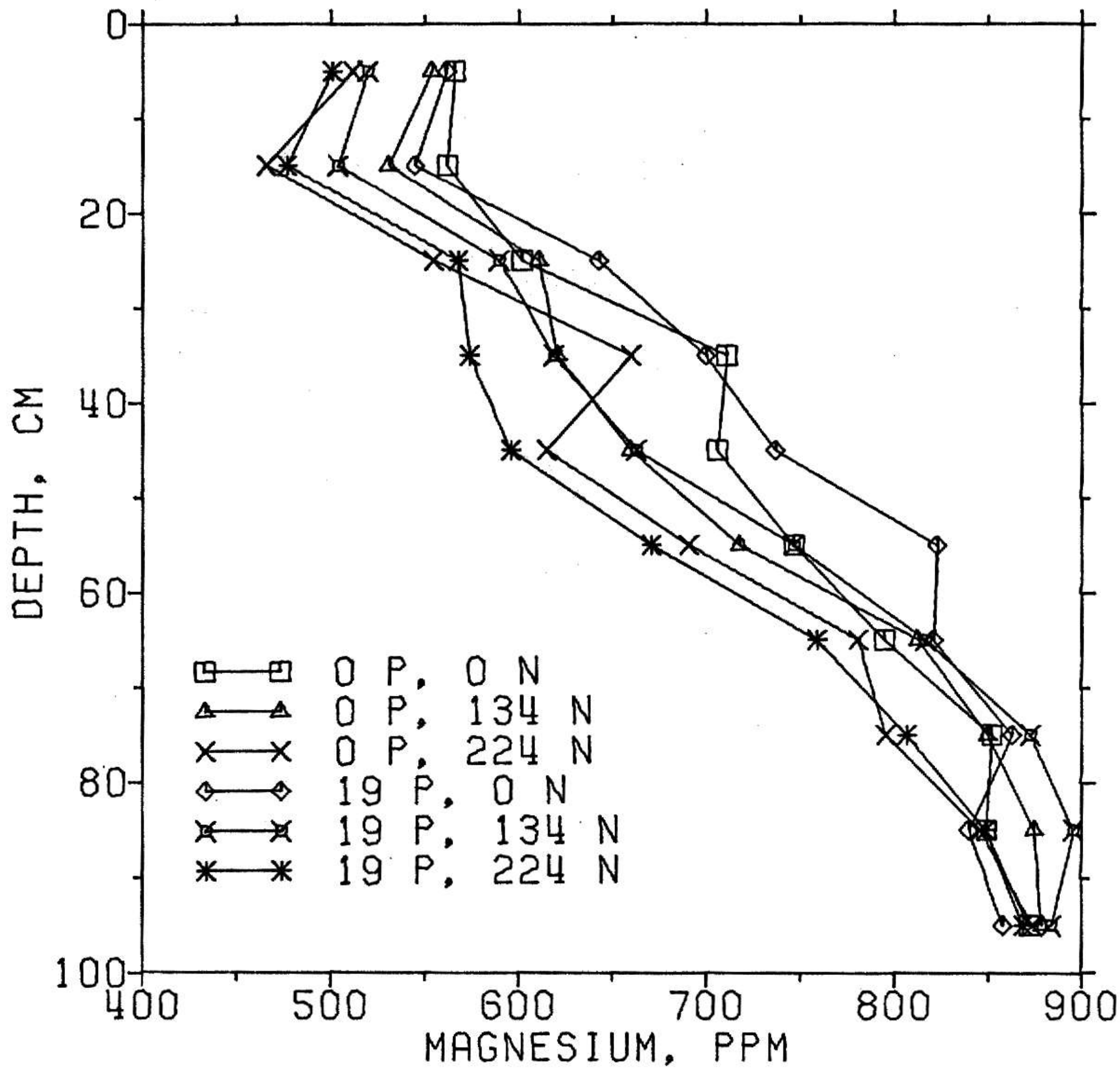

Fig. 9. Extractable soil magnesium as affected by nitrogen and phosphorus treatments.

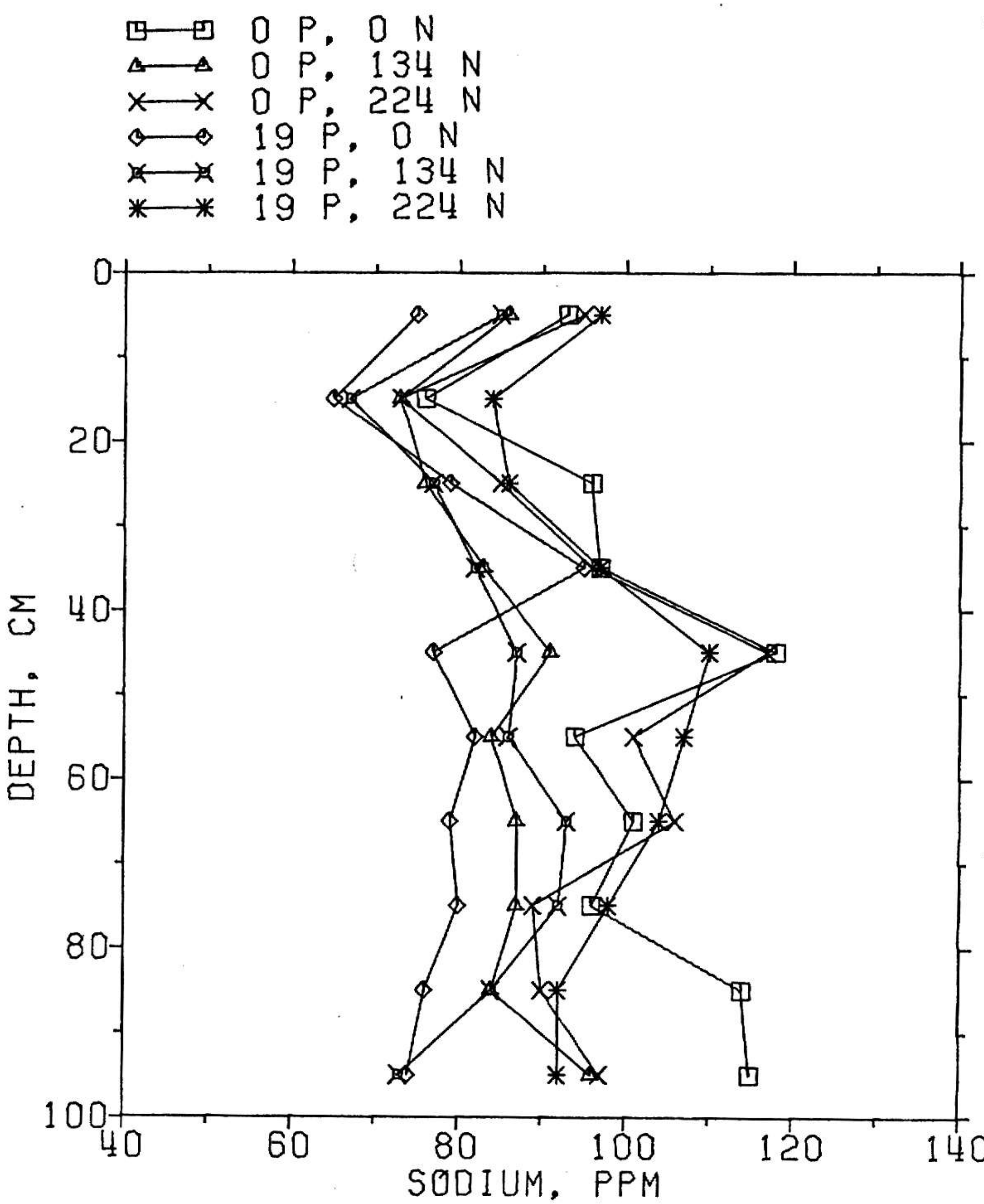

Fig. 10. Extractable soil sodium as affected by nitrogen and phosphorus treatments.

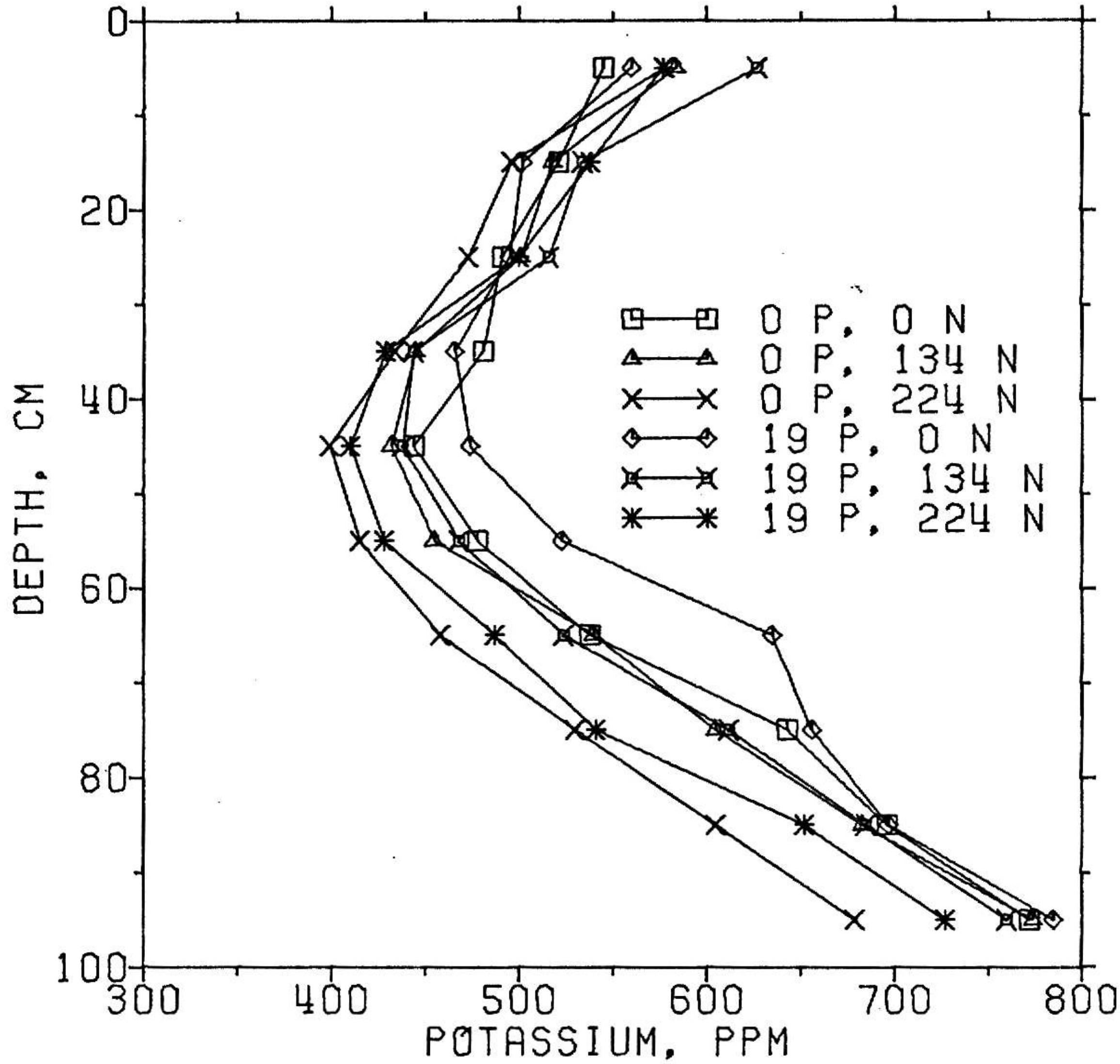

Fig. 11. Extractable soil potassium as affected by nitrogen and phosphorus treatments.

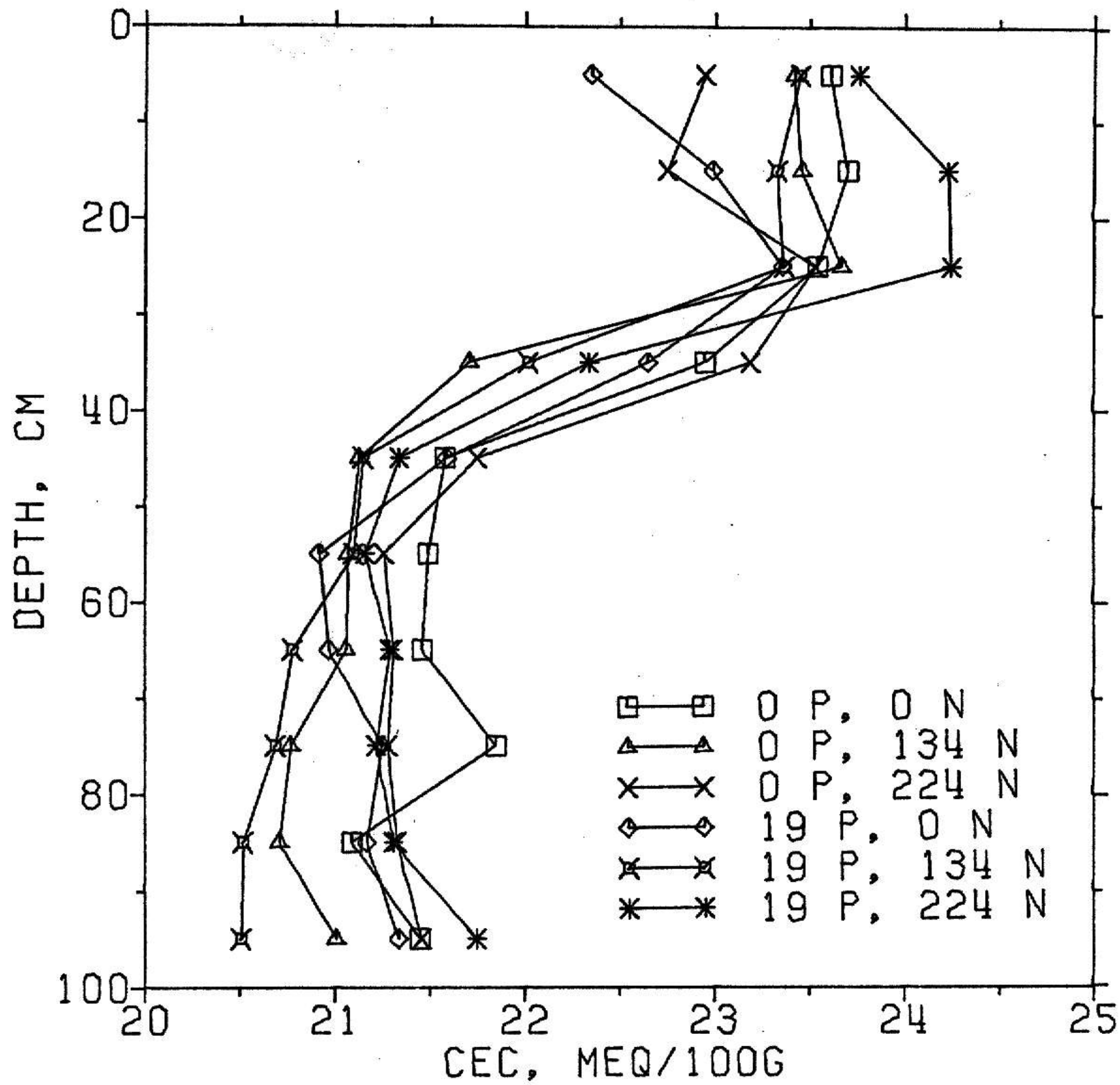

Fig. 12. Soil cation exchange capacity as affected by nitrogen and phosphorus treatments.

amount of available copper in the soil. Copper concentrations were highest at the 25-35 cm depth. At the lower depths (35-50 cm) added phosphorus resulted in decreased amounts of available copper as shown in Figure 13. Low copper concentrations in the surface 10 cm are probably due to crop uptake and removal. Soil DTPA-extractable copper was considered to be adequate with a grand mean of 0.67 ppm.

Extractable Iron

Regardless of treatment, DTPA-extractable iron decreased with depth as shown in Figure 14. Iron availability is often a problem in calcareous soils in Kansas, especially with sorghum, soybeans, pinto beans, and corn, and the decreased extractability with depth is probably due to increasing pH and soil calcium carbonate content. Nitrogen treatments had significant effects on extractable iron, and the same pattern of concentration developed as was noted with copper. The effect of phosphorus was insignificant, but some suggestion existed of an increase in extractable iron with P applications (Table 6). Extractable iron concentrations ranged from 3-7 ppm, which ranks in the medium to high category in Kansas.

Extractable Manganese

DTPA-extractable manganese levels were high enough that no deficiency problems should exist. Manganese concentrations varied from approximately 3-18 ppm. Manganese was affected by nitrogen and phosphorus treatments as well as depth, as shown in Table 6. The increase in extractable manganese with nitrogen was probably due to secondary effects of high nitrogen rates on soil pH and $CaCO_3$ content near the soil surface. Phosphorus addition decreased available manganese throughout the profile. This may have been due more to increased uptake and removal by the crop than to any other factor. There was a decrease in available manganese with depth regardless of treatment as shown in Figure 15.

Table 6. Mean values for copper, iron, manganese, and zinc as affected by N rate, P application, or soil depth.

Treatment kg/ha	copper ppm	iron ppm	manganese ppm	zinc ppm
0 N	.671	3.99	7.51	1.03
134 N	.697	5.07	7.56	1.08
224 N	.652	4.37	8.49	0.84
$LSD_{.05}$	NS	0.39	0.69	NS
0 P	.679	4.36	8.40	0.99
19 P	.668	4.59	7.31	0.97
$LSD_{.05}$	NS	NS	0.57	NS
Depth, cm				
0				
0-10	.637	5.48	13.03	1.84
10-20	.661	5.30	10.16	2.07
20-30	.713	4.52	7.19	0.74
30-40	.704	3.66	4.80	0.14
40-50	.652	3.42	4.08	0.13
$LSD_{.05}$	.048	0.50	0.89	0.45

Extractable Zinc

DTPA-extractable zinc concentrations varied from nearly none up to 2.5 ppm. The reduction in soil zinc levels was quite pronounced below 30 cm. This is a prime reason why zinc deficiency symptoms commonly develop in crops growing on newly leveled land where the subsoil is exposed at the surface. Eleven kg/ha of zinc were applied to all plots in 1968 and 1969 to offset a low soil zinc condition. The decrease in zinc in the upper 15 cm is probably due to crop removal since that period of time (Figure 16). Available soil zinc concentration with depth seemed closely correlated with expected pH effect on zinc availability. No clear differences due to treatment are evident in data presented in Table 6.

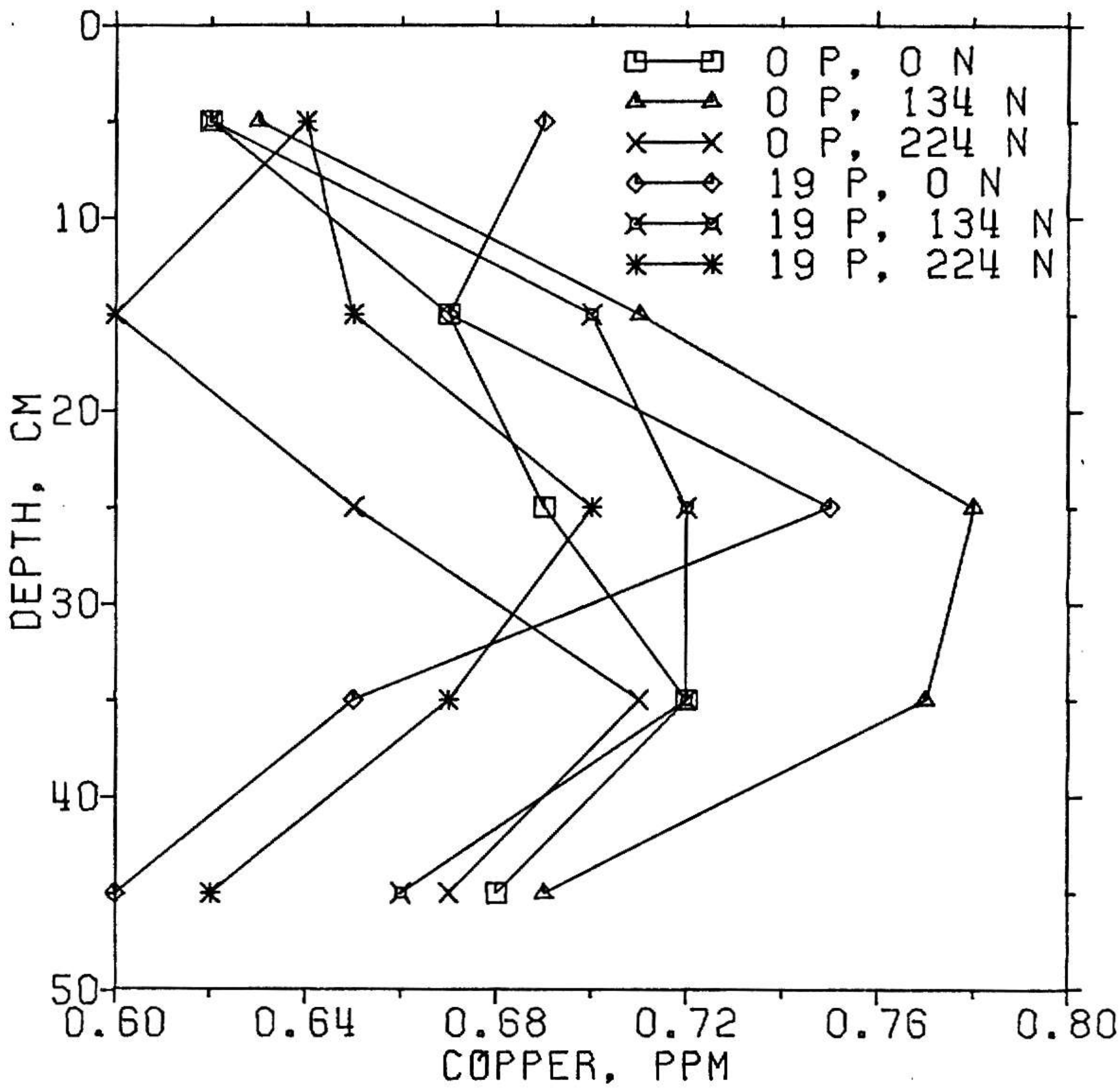

Fig. 13. DTPA-extractable soil copper as affected by nitrogen and phosphorus treatments.

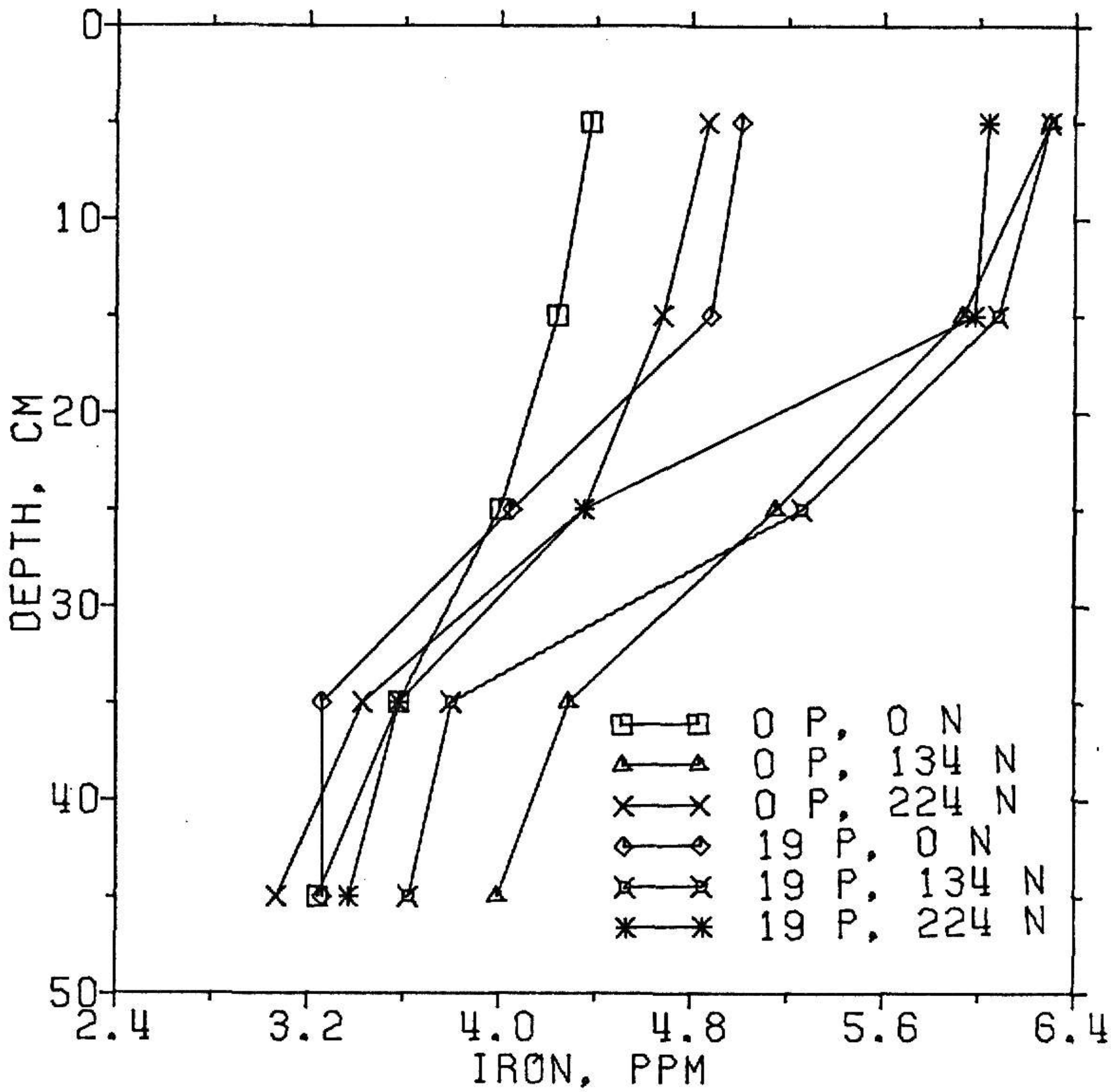

Fig. 14. DTPA-extractable soil iron as affected by nitrogen and phosphorus treatments.

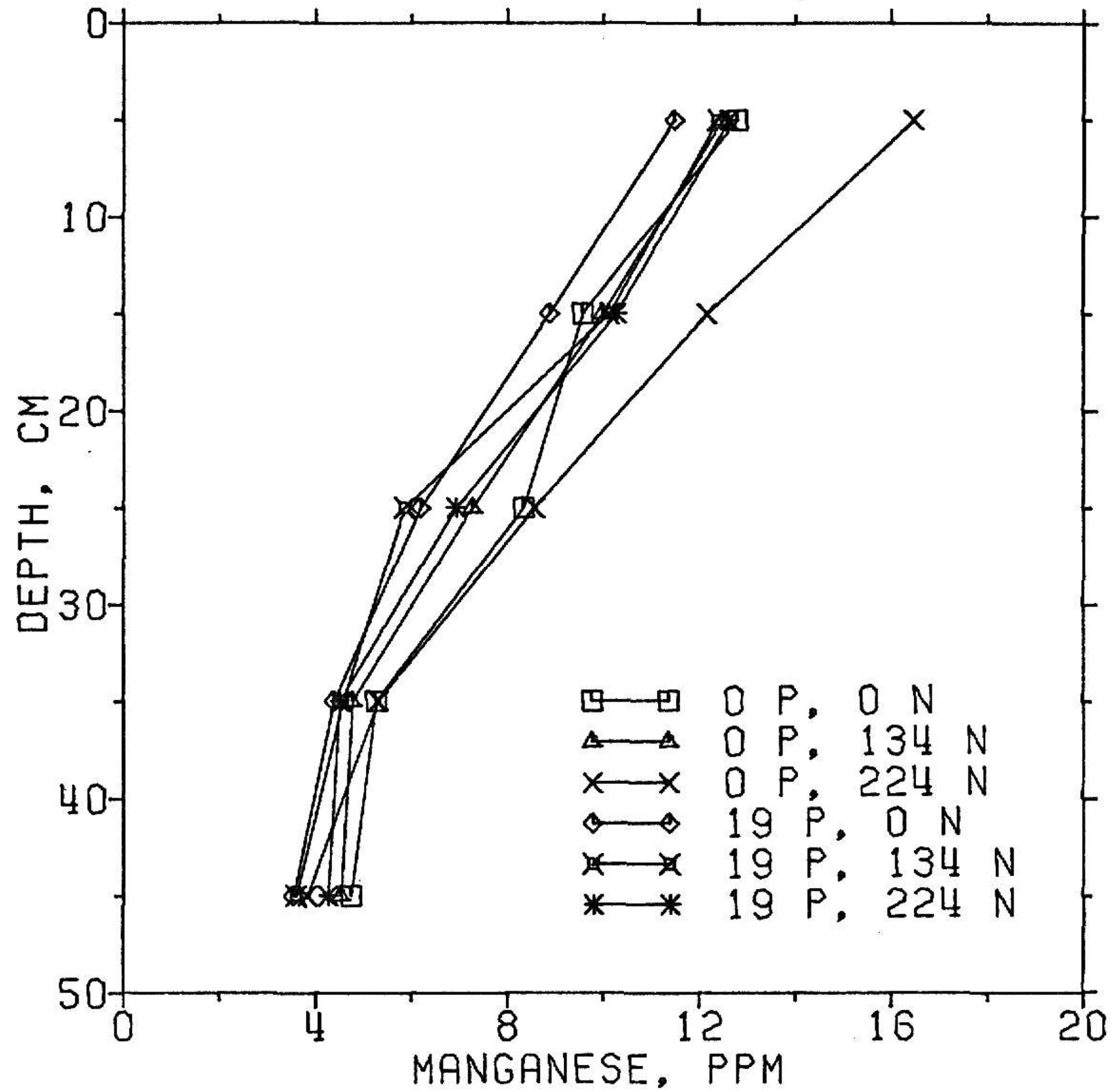

Fig. 15. DTPA-extractable soil manganese as affected by nitrogen and phosphorus treatments.

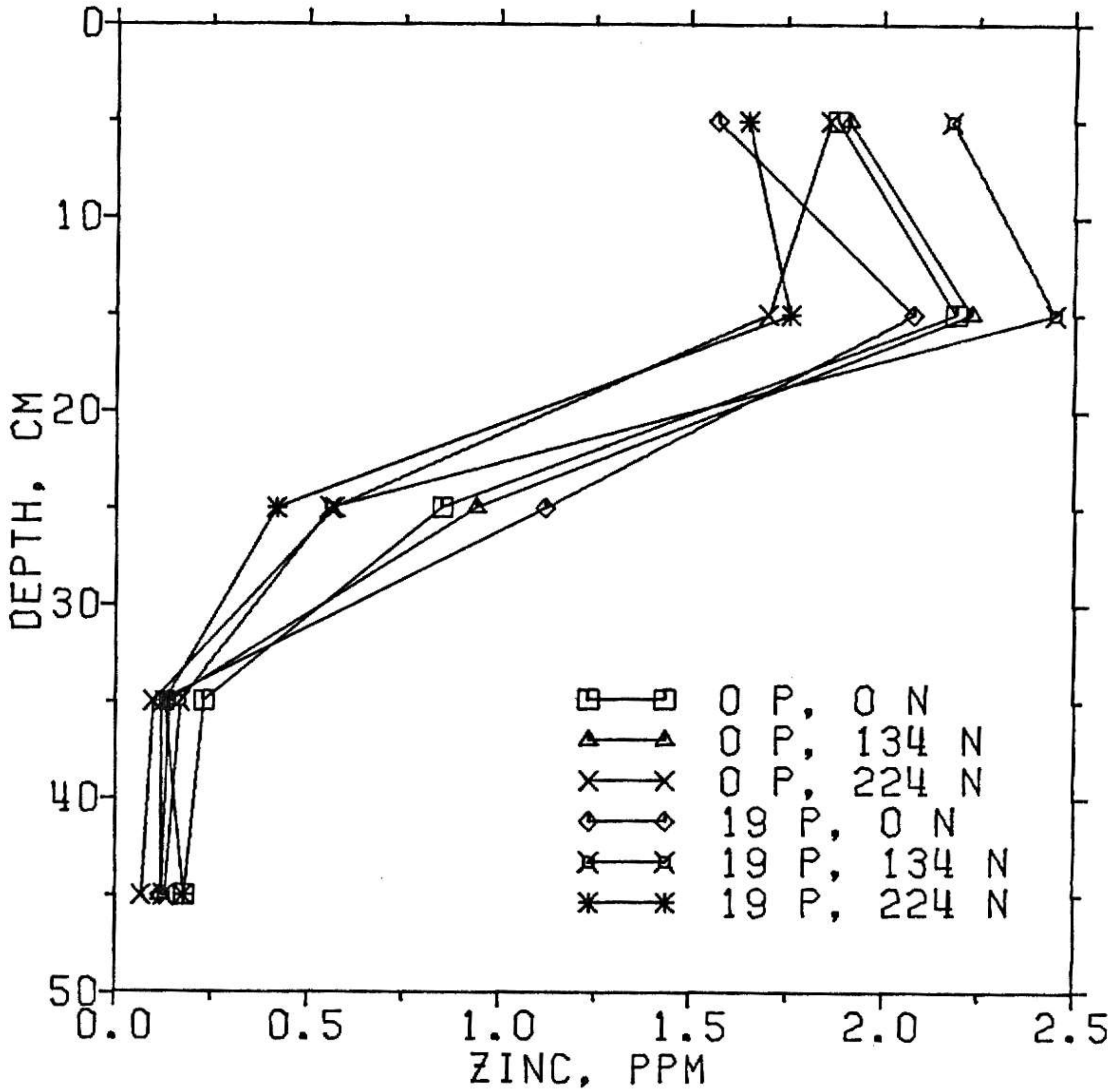

Fig. 16. DTPA-extractable soil zinc as affected by nitrogen and phosphorus treatments.

Total Carbon

In analysis for total soil carbon, carbonate-carbon, and organic carbon, only the four extreme treatments were included (Figure 17). Applications of 224 kg N/ha decreased total soil carbon, while addition of 19 kg P/ha increased amounts of total soil carbon. However, the effects of these treatments were not significant as shown in Table 7. Total carbon concentration increased with depth, reaching a maximum near the 35-55 cm depth, and then declined. Total carbon varied from 1.0 to nearly 2.2%.

Carbonate-carbon

Soil carbonate-carbon varied from 0.3-1.8%. There were large concentrations of carbonate-carbon at the 40-60 cm depth in the profile as shown in Figure 18. This accumulation is probably due to downward movement of soluble calcium and magnesium carbonates through the leaching process. No consistent differences due to treatment were apparent, but there was a general trend for carbonate-carbon to decrease with nitrogen treatment, especially in the upper 25 cm. Depth means, as shown in Table 7, indicate significant differences in carbonate-carbon concentration with profile depth.

Organic Carbon

Organic carbon decreased with depth as shown in Figure 19. This was due to decreased organic matter content with depth. There was a general trend for the nitrogen applications to increase soil organic carbon, especially in the upper 20 cm, but this effect was not significant (Table 7). Organic carbon decreased with the addition of 19 kg/ha of phosphorus, but this trend was evident only under the 224 kg/ha nitrogen application.

Table 7. Mean values for total carbon, carbonate-carbon, and organic carbon as affected by N rate, P application, or soil depth.

Treatment kg/ha	total carbon %	carbonate-carbon %	organic carbon %
0 N	1.54	1.22	0.32
224 N	1.51	1.17	0.34
$LSD_{.05}$	NS	NS	NS
0 P	1.52	1.17	0.35
19 P	1.54	1.22	0.32
$LSD_{.05}$	NS	NS	0.02
Depth, cm			
0-5	1.20	0.46	0.74
5-10	1.14	0.48	0.66
10-15	1.15	0.48	0.67
15-20	1.08	0.47	0.61
20-25	1.21	0.67	0.54
25-30	1.46	1.01	0.46
30-35	1.68	1.28	0.41
35-40	1.96	1.56	0.39
40-45	2.06	1.67	0.39
45-50	1.93	1.71	0.22
50-55	1.90	1.65	0.25
55-60	1.79	1.60	0.20
60-65	1.81	1.56	0.25
65-70	1.66	1.46	0.21
70-75	1.52	1.40	0.12
75-80	1.46	1.34	0.13
80-85	1.41	1.34	0.10
85-90	1.44	1.29	0.16
90-95	1.34	1.26	0.09
95-100	1.33	1.23	0.11
$LSD_{.05}$	0.19	0.17	0.08

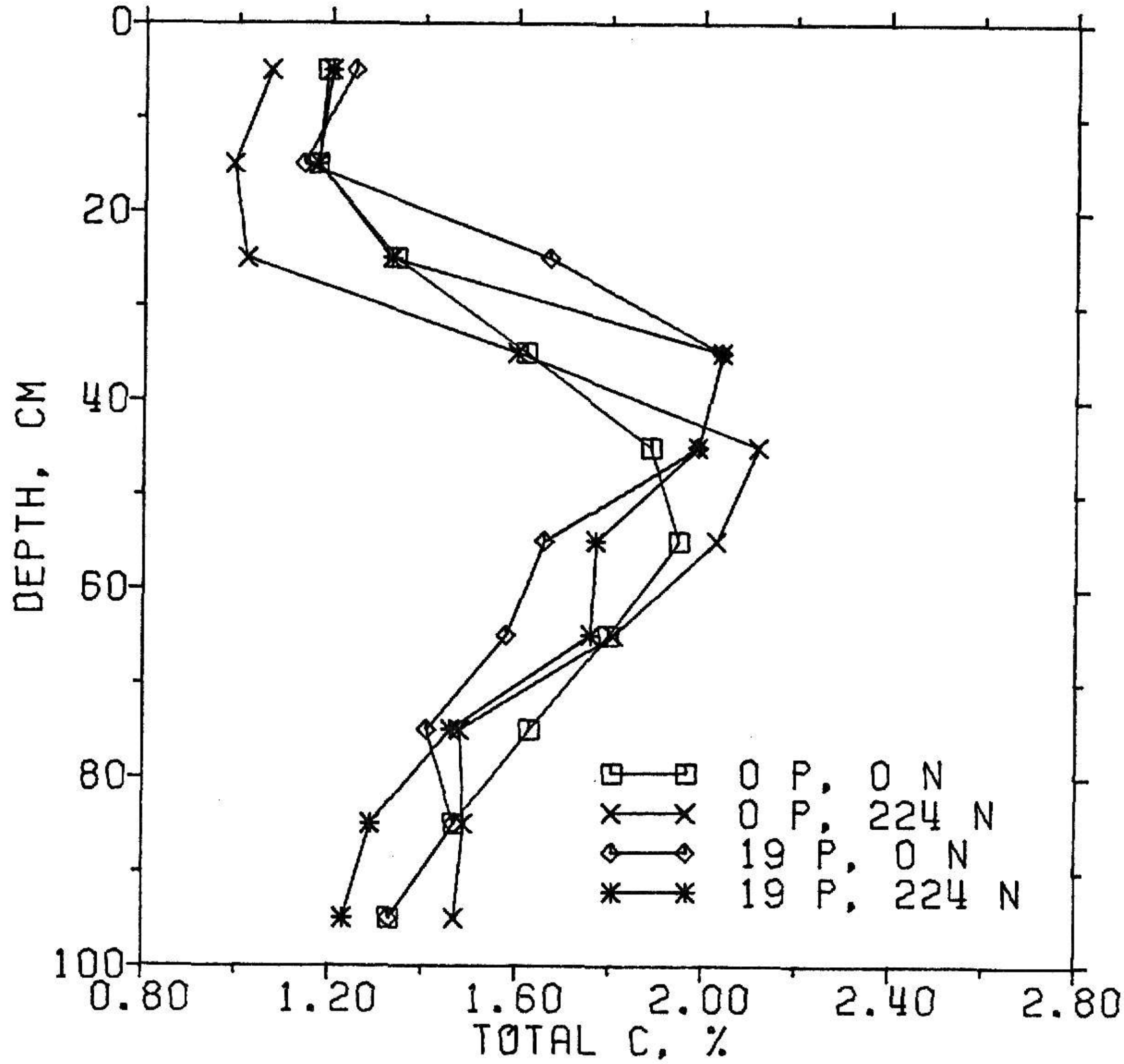

Fig. 17. Total soil carbon as affected by nitrogen and phosphorus treatments.

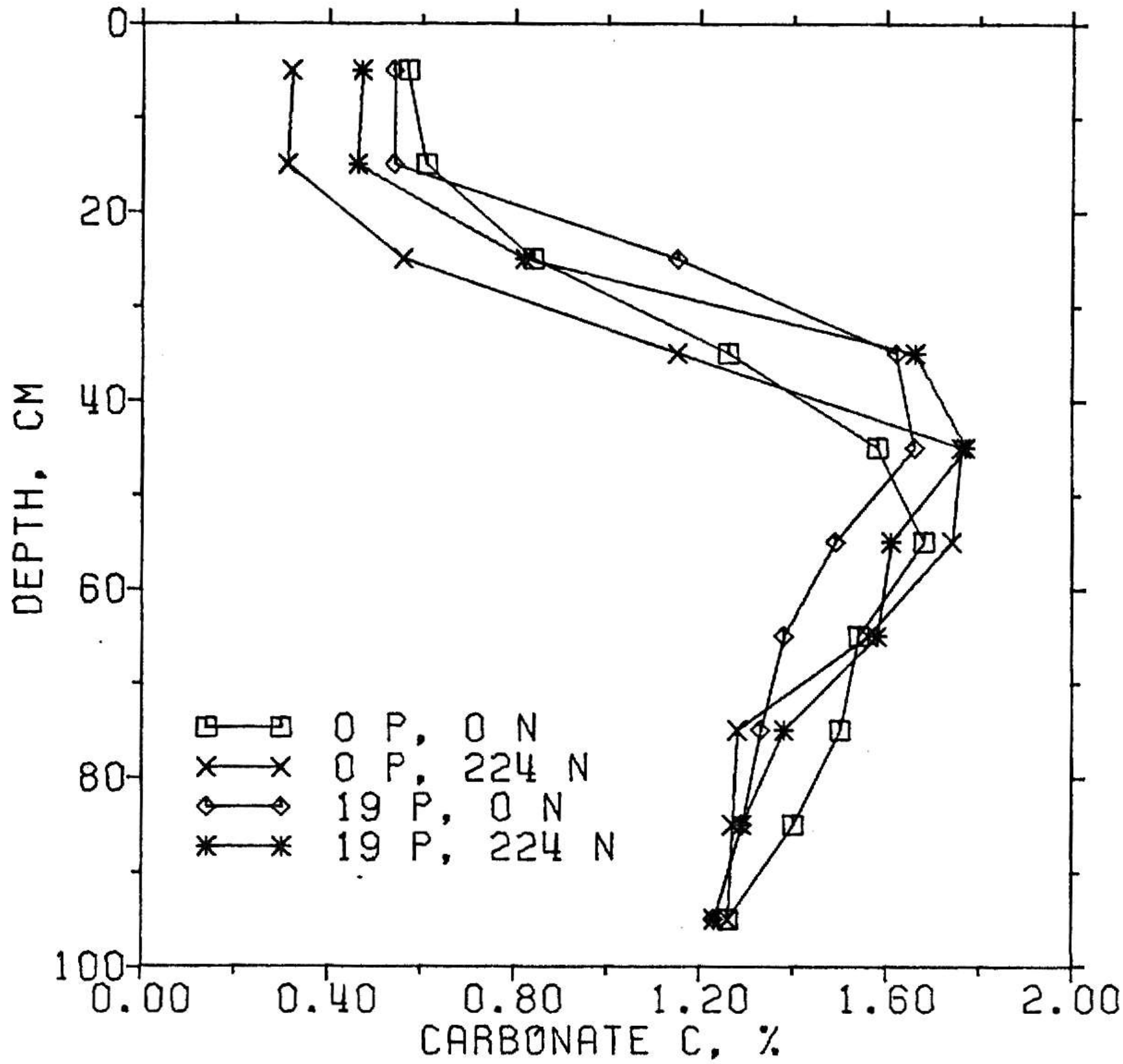

Fig. 18. Soil carbonate-carbon as affected by nitrogen and phosphorus treatments.

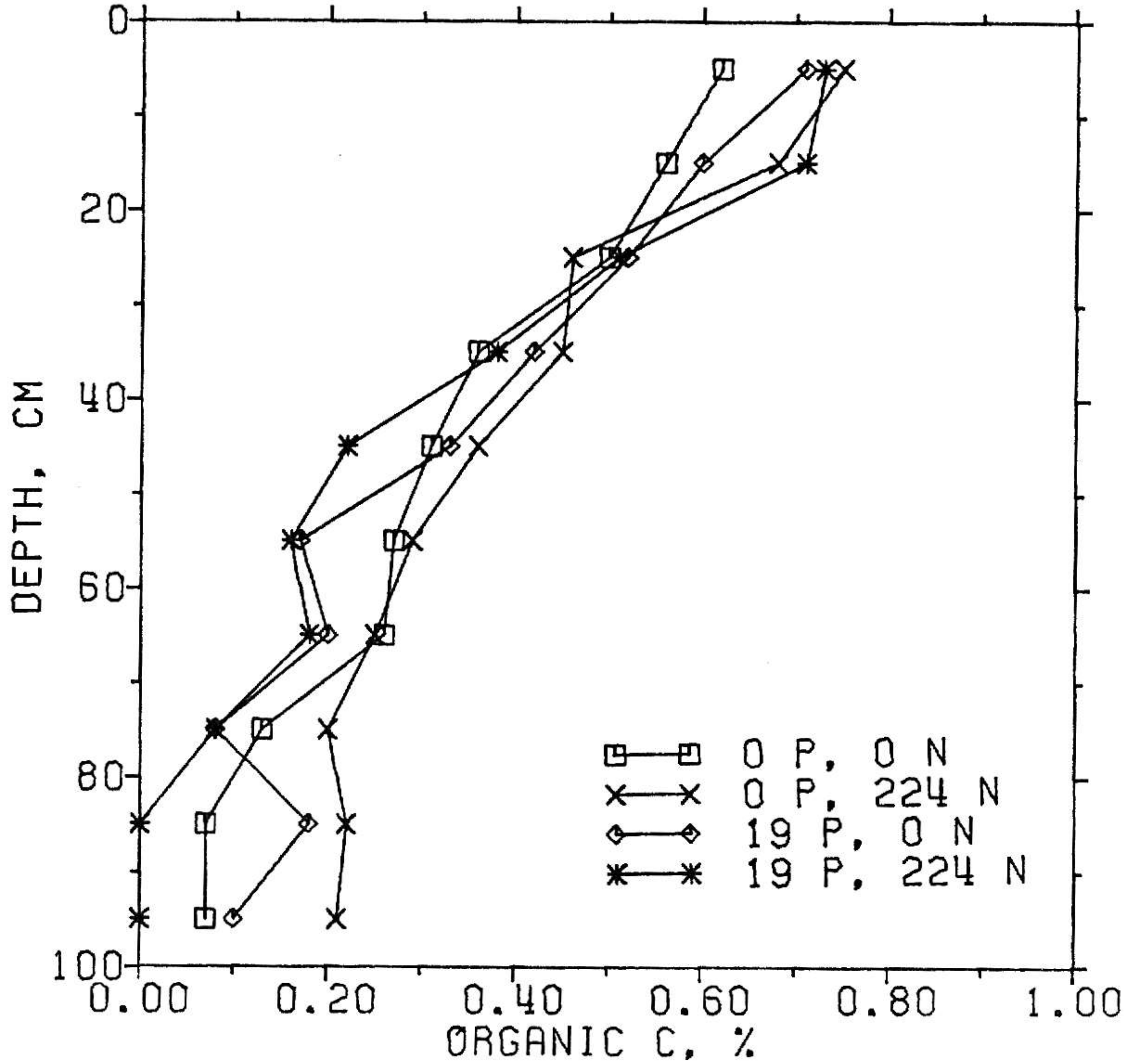

Fig. 19. Soil organic carbon as affected by nitrogen and phosphorus treatments.

SUMMARY AND CONCLUSION

The results of this study indicate that continuous applications of nitrogen and phosphorus fertilizer have had measurable effects on chemical properties of the Richfield soil.

Unaccountably high concentrations of ammonium-nitrogen indicate either possible ammonium-N contamination of the samples or build-up of ammonium-N in the samples through a microbiological process such as mineralization without subsequent nitrification. Depending upon the source of the ammonium-N, many questions concerning the nitrogen status of this soil remain unanswered. More research in this area is needed since ammonium-N is included in the Kansas test for available soil nitrogen.

Nitrate-nitrogen levels in the profile indicate little accumulation or leaching of this form of nitrogen. Nitrogen and phosphorus treatments increased the amount of nitrate-nitrogen in the soil as fertilizer rates increased. Fertilization with nitrogen certainly has not produced accumulations of NO_3^--N in the soil which could pose a threat to groundwater quality. This demonstrates that adherance to recommended rates of nitrogen fertilization tends to eliminate the problem of soil nitrate-N loss due to leaching.

Nitrogen applications had no measurable effect on total soil nitrogen, but the addition of 19 kg/ha of phosphorus significantly decreased total soil nitrogen.

Both nitrogen and phosphorus applications significantly decreased soil pH, even though measured differences were very small. Since this soil contains such large amounts of calcium carbonate, no forseeable drastic change in pH should take place using the present rates of fertilization. Soil pH slowly increased with depth and reached a maximum of about 8.4 at the 400 cm depth due to the presence of free calcium carbonate.

Weak Bray extractable phosphorus decreased as nitrogen rates increased, and increased markedly when 19 kg P/ha were applied. Little movement of fertilizer phosphorus is indicated due to sharp decreases in extractable phosphorus with depth.

An interesting trend in this study was that the application of 19 kg P/ha decreased total soil nitrogen and organic carbon. This would lead one to speculate that soil organic matter content also decreased. Though this was not measured, soil CEC did decrease slightly, and surface CEC is closely related to organic matter content.

Heavy rates of nitrogen fertilizer tended to decrease extractable calcium and magnesium levels in the soil. Phosphorus had no effect on extractable calcium and magnesium concentrations. Both calcium and magnesium concentrations increased considerably with depth. The Ca:Mg ratio in this soil is quite high, exceeding 16:1 near the soil surface and approaching 27:1 lower in the profile. The soil K:Mg ratio varies from 1:1 at the surface to 1:1.5 at the 50 cm depth. This high magnesium content may explain the lack of response of corn to applied magnesium that researchers have found recently in Kansas.[2]

Extractable soil potassium content decreased when increasing nitrogen rates were applied, which was probably due to increased plant removal of soil K. Addition of 19 kg P/ha produced an increase in extractable soil potassium, which was probably due to the effect of phosphorus on lowering soil pH and thereby increasing availability of soil K.

---

[2]Whitney, D. A. and R. Ellis, Jr. 1973. Kansas Fertilizer Research Report of Progress. 202:124.

Cation exchange capacity, which varied from 20-25 meq/100 g soil, decreased with depth. Soil CEC was affected by nitrogen treatment, but no trend was apparent.

Higher applications of nitrogen seemed to generally increase the availability of iron and manganese, while phosphorus only affected the availability of soil manganese. Levels of all micronutrients were adequate in the upper 15 cm of soil. Zinc levels below 30 cm were quite low.

Nitrogen and phosphorus had inverse effects on all forms of soil carbon, but measurable effects were quite small and usually insignificant. Carbonate-carbon comprised from 75-80% of the total soil carbon when averaged across all depths.

The results of this study indicate that applied phosphorus effects on soil chemical properties are more significant to date than the effects of nitrogen. When high rates of nitrogen are used, decreases in soil potassium are quite apparent. This would indicate that potassium fertilization may eventually be necessary on areas where high nitrogen rates have been applied for some time, especially when large amounts of forage along with grain are removed, such as is the case with silage production.

LITERATURE CITED

1. Abruna, F., R. W. Pearson, and C. B. Elkins. 1958. Quantitative evaluation of soil reaction and base status changes resulting from field applications of residually acid-forming nitrogen fertilizers. Soil Sci. Soc. Amer. Proc. 22:539-542.

2. Adams, W. E., R. W. Pearson, W. A. Jackson, and R. A. McCreery. 1967. Influence of limestone and nitrogen on soil pH and coastal bermudagrass yield. Agron. J. 59:450-453.

3. Allison, F. E., M. Kefauver, and E. M. Roller. 1953. Ammonium fixation in soils. Soil Sci. Soc. Amer. Proc. 17:107-110.

4. Allison, F. E. 1955. The engima of soil nitrogen balance sheets. Adv. Agron. 7:213-250.

5. Allison, L. E. 1965. Organic carbon. In C. A. Black (ed.) Methods of soil analysis. II. Chemical and microbiological properties. Agronomy 9:1367-1378.

6. Allison, L. E., W. B. Bollen, and C. D. Moodie. 1965. Total carbon. In C. A. Black (ed.) Methods of soil analysis. II. Chemical and microbiological properties. Agronomy 9:1346-1366.

7. Allison, L. E. and C. D. Moodie. 1965. Carbonate. In C. A. Black (ed.) Methods of soil analysis. II. Chemical and microbiological properites. Agronomy 9:1379-1396.

8. Arnold, P. W. 1954. Losses of nitrous oxide from soil. J. Soil Sci. 5:116-128.

9. Bates, T. E. and S. L. Tisdale. 1957. The movement of nitrate-nitrogen through columns of coarse-textured soil materials. Soil Sci. Soc. Amer. Proc. 21:525-528.

10. Belo, J. A. O. 1970. Determination of total carbon by dry combustion and its relation to forms of soil nitrogen as measured in the laboratory and in the greenhouse. Ph.D. thesis. Michigan State University.

11. Bingham, F. T. and M. J. Garber. 1960. Solubility and availability of micronutrients in relation to P fertilization. Soil Sci. Soc. Amer. Proc. 24:209-213.

12. Boawn, L. C., C. E. Nelson, F. G. Viets, Jr., and C. L. Crawford. 1960. Nitrogen carrier and nitrogen rate influence on soil properties and nutrient uptake by crops. Washington Ag. Exp. Sta. Bulletin 614.

13. Boswell, F. C. and O. E. Anderson. 1964. Nitrogen movement in undisturbed profiles of fallowed soils. Agron. J. 56:278-281.

14. Bremner, J. M. and K. Shaw. 1958. Denitrification in soil. II. Factors affecting denitrification. J. Agr. Sci. 51:40-52.

15. Bremner, J. M. and D. R. Keeney. 1965. Steam distillation methods for determination of ammonium, nitrate, and nitrite. Anal. Chem. Acta. 32:485-495.

16. Broadbent, F. E. 1951. Denitrification in some California soils. Soil Sci. 72:129-137.

17. Broadbent, F. E. and B. F. Stojanovic. 1952. The effect of partial pressure of oxygen in some soil nitrogen transformations. Soil Sci. Soc. Amer. Proc. 16:359-363.

18. Broadbent, F. E. and F. E. Clark. 1965. Denitrification. In W. V. Bartholomew and F. E. Clark (ed.) Soil nitrogen. Agronomy 10:357-362.

19. Broadbent, F. E. and K. B. Tyler. 1965. Effect of pH on N immobilization in two California soils. Plant and Soil 23:314-322.

20. Brown, A. A., James Quick, and J. L. Eddings. 1971. A comparison of analytical methods for soil zinc. Soil Sci. Soc. Amer. Proc. 35:105-107.

21. Burd, J. S. 1948. Chemistry of the phosphate ion in soil systems. Soil Sci. 65:227-247.

22. Clark, F. E., W. E. Beard, and D. H. Smith. 1960. Dissimilar nitrifying capacities of soils in relation to losses of applied nitrogen. Soil Sci. Soc. Amer. Proc. 24:50-54.

23. Clevenger, C. B and L. G. Willis. 1935. Immediate effects of fertilization upon soil reaction. Agron. J. 27:833-846.

24. Cole, C. V., S. R. Olsen, and C. O. Scott. 1957. The nature of phosphate sorption by calcium carbonate. Soil Sci. Soc. Amer. Proc. 17:352-356.

25. Cornfield, A. H. 1952. The mineralization of the nitrogen of soils during incubation: Influence of pH, total nitrogen, and organic carbon content. J. Sci. Food Agric. 3:343-349.

26. Cornfield, A. H. 1959. Mineralization, during incubation, of the organic nitrogen compounds in soils as related to soil pH. J. Sci. Food Agric. 10:27-28.

27. Dancer, W. S., L. A. Peterson, and G. Chesters. 1973. Ammonification and nitrification of N as influenced by soil pH and previous N treatments. Soil Sci. Soc. Amer. Proc. 37:67-69.

28. Dodge, D. A. and H. E. Jones. 1947. The effect of long-time fertility treatments on the nitrogen and carbon content of a prairie soil. Soil Sci. Soc. Amer. Proc. 12:294.

29. Fuller, W. H. 1963. Reactions of nitrogenous fertilizers in calcareous soils. Agr. Food Chem. 11:188-193.

30. Gardner, W. R. 1965. Movement of nitrogen in soil. In W. V. Bartholomew and F. E. Clark (ed.) Soil nitrogen. Agronomy 10:550-572.

31. Grunes, D. L. 1959. Effect of nitrogen on the availability of soil and fertilizer phosphorus to plants. Adv. in Agron. 11:361-396.

32. Haas, H. J., C. E. Evans, and E. F. Miles. 1957. Nitrogen and carbon changes in great plains soils as influenced by cropping and soil treatments. U. S. D. A. Tech. Bulletin 1164.

33. Hannapel, R. J., W. H. Fuller, and R. H. Fox. 1964. Phosphorus movement in a calcareous soil. II. Soil microbial activity and organic phosphorus movement. Soil Sci. 97:421-427.

34. Herron, G. M., G. L. Terman, A. F. Drier, and R. A. Olson. 1968. Residual nitrate-N in fertilized deep loess-derived soils. Agron. J. 60:477-482.

35. Hiltbold, A. E. and F. Adams. 1960. Effect of nitrogen volatilization on soil acidity changes due to applied nitrogen. Soil Sci. Soc. Amer. Proc. 24:45-47.

36. Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall Inc. Sixth printing, 1970, by the author, Department of Soil Science, University of Wisconsin, Madison, Wisconsin.

37. Jannson, S. L. and F. E. Clark. 1952. Losses of nitrogen during decomposition of plant material in the presence of inorganic nitrogen. Soil Sci. Soc. Amer. Proc. 16:330-334.

38. Jenny, J., A. D. Ayers, and J. S. Hosking. 1945. Comparative behavior of ammonia and ammonium salts in soils. Hilgardia 16:429-457.

39. Jewitt, T. N. 1942. Loss of ammonia from ammonium sulfate applied to alkaline soils. Soil Sci. 54:401-409.

40. Johnston, W. R., F. Ittihadieh, R. M. Daum, and A. F. Pillsbury. 1965. Nitrogen and phosphorus in tile drainage effluent. Soil Sci. Soc. Amer. Proc. 29:287-289.

41. Jones, E. J. 1951. Loss of elemental nitrogen from soils under anaerobic conditions. Soil Sci. 71:193-196.

42. Jurinak, J. J. and N. Bauer. 1956. Thermodynamics of zinc adsorption on calcite, dolomite, and magnesite type minerals. Soil Sci. Soc. Amer. Proc. 20:466-471.

43. Kefauver, M. and F. E. Allison. 1957. Nitrite reduction by Bacterium denitrificans in relation to oxidation-reduction potential and oxygen tension. J. Bact. 73:8-14.

44. Kresge, C. B. and D. P. Satchell. 1960. Gaseous loss of ammonia from nitrogen fertilizers applied to soils. Agron. J. 52:104-107.

45. Larson, K. L., J. F. Carter, and E. H. Vasey. 1971. Nitrate-nitrogen accumulation under bromegrass sod fertilized annually at six levels of nitrogen for 15 years. Agron. J. 63:527-528.

46. Leo, W. M., T. E. Odland, and R. S. Bell. 1959. Effect on soils and crops of long continued use of sulfate of ammonia and nitrate of soda with and without lime. Rhode Island Agr. Exp. Sta. Bulletin 344.

47. Lindsay, W. L. and W. A. Norvell. 1969. Development of a DTPA micronutrient soil test. Agron. Abst. p. 84.

48. Loewenstein, H., L. E. Engelbert, O. J. Attoe, and O. N. Allen. 1957. Nitrogen loss in gaseous form from soils as influenced by fertilizers and management. Soil Sci. Soc. Amer. Proc. 21:397-400.

49. Lorenz, O. A. and C. M. Johnson. 1953. Nitrogen fertilization as related to the availability of phosphorus in certain California soils. Soil Sci. 75:119-129.

50. Martin, J. P. and H. D. Chapman. 1951. Volatilization of ammonia from surface-fertilized soils. Soil Sci. 71:25-34.

51. Meek, B. D. and A. J. MacKenzie. 1965. The effect of nitrite and organic matter on aerobic gaseous losses of nitrogen from calcareous soil. Soil Sci. Soc. Amer. Proc. 29:176-178.

52. Meek, B. D., L. B. Grass, and A. J. MacKenzie. 1969. Applied nitrogen losses in relation to oxygen status of soils. Soil Sci. Soc. Amer. Proc. 33:575-578.

53. Meyer, R. D., R. A. Olson, and H. G. Rhoades. 1961. Ammonia losses from fertilized Nebraska soils. Agron. J. 53:241-244.

54. Moe, P. G., J. V. Mannering, and C. B. Johnson. 1968. A comparison of nitrogen losses from urea and ammonium nitrate in surface runoff water. Soil Sci. 105:428-433.

55. Moore, D. G. 1960. Nitrogen movement in soil as affected by time of application, form of nitrogen, and fixation. Diss. Abstracts 21:414-415.

56. Morrill, L. G. and J. E. Dawson. 1967. Patterns observed for the oxidation of ammonium to nitrate by soil organisms. Soil Sci. Soc. Amer. Proc. 31:757-760.

57. Navrot, J. and S. Ravikovitch. 1969. Zinc availability in calcareous soils: III. The level and properties of calcium in soils and its influence on zinc availability. Soil Sci. 108:30-37.

58. Nelson, C. E. 1953. Methods of applying ammonium nitrate fertilizer on field corn, and a study of the movement of NH_4^+ and NO_3^- nitrogen in the soil under irrigation. Agron. J. 45:154-157.

59. Olsen, R. J., R. F. Hensler, O. J. Attoe, S. A. Witzel, and L. A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate-nitrogen through soil profiles. Soil Sci. Soc. Amer. Proc. 34:448-452.

60. Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U. S. D. A. Circular 939.

61. Olsen, S. R., F. S. Watanabe, H. R. Cosper, W. E. Larson, and L. B. Nelson. 1954. Residual phosphorus availability in long-time rotation on calcareous soils. Soil Sci. 78:141-151.

62. Owensby, C. E., K. L. Anderson, and D. A. Whitney. 1969. Some chemical properties of a silt loam soil after 20 years' nitrogen and phosphorus fertilization of smooth bromegrass. Soil Sci. 108:24-29.

63. Patrick, W. H. Jr. and R. Wyatt. 1964. Soil nitrogen loss as a result of alternate submergence and drying. Soil Sci. Soc. Amer. Proc. 28:647-653.

64. Pearson, R. W., F. Abruna, and J. Vicente-chandler. 1962. Effect of lime and nitrogen applications on downward movement of calcium and magnesium in two humid tropical soils of Puerto Rico. Soil Sci. 93: 77-82.

65. Peterson, L. A. and O. J. Attoe. 1965. Importance of soil nitrates in determination of need and recovery of fertilizer nitrogen. Agron. J. 57:572-574.

66. Pierre, W. H. 1928. Nitrogenous fertilizers and soil acidity: I. Effects of various nitrogeneous fertilizers on soil reaction. Agron. J. 20:254-269.

67. Pierre, W. H., J. R. Webb, and W. D. Shrader. 1971. Quantitative effects of nitrogen fertilizer on the development and downward movement of soil acidity in relation to level of fertilization and crop removal in a continuous corn cropping system. Agron. J. 63:291-297.

68. Pratt, P. F., W. W. Jones, and H. D. Chapman. 1956. Changes in phosphorus in an irrigated soil during 28 years of differential fertilization. Soil Sci. 82:295-306.

69. Pratt, P. F. and J. D. Chapman. 1961. Gains and losses of mineral elements in an irrigated soil during a 20-year lysimeter investigation. Hilgardia 30:445-467.

70. Pratt, P. F., W. W. Jones, and V. E. Hunsaker. 1972. Nitrate in deep soil profiles in relation to fertilizer rates and leaching volume. J. Environmental Quality 1:97-102.

71. Ray, H. E., J. M. MacGregor, and E. L. Schmidt. 1957. Movement of ammonium nitrogen in soils. Soil Sci. Soc. Amer. Proc. 21:309-312.

72. Rennie, D. A. and R. J. Soper. 1958. The effect of nitrogen additions on fertilizer-phosphorus availability. II. J. Soil Sci. 9:155-167.

73. Robinson, J. B. D. 1957. The critical relationship between soil moisture content in the region of wilting point and the mineralization of natural soil nitrogen. J. Agr. Sci. 49:100-105.

74. Schwartzbeck, R. A., J. M. MacGregor, and E. L. Schmidt. 1961. Gaseous nitrogen losses from nitrogen fertilized soils measured with infrared and mass spectroscopy. Soil Sci. Soc. Amer. Proc. 25:186-189.

75. Simpson, J. R. 1960. The mechanism of surface nitrate accumulation on a bare fallow soil in Uganda. J. Soil Sci. 11:45-60.

76. Smith, D. H. and F. E. Clark. 1960. Volatile losses of nitrogen from acid or neutral soils or solutions containing nitrate and ammonium ions. Soil Sci. 90:86-92.

77. Stephens, D. 1962. Upward movement of nitrate in a bare soil in Uganda. J. Soil Sci. 13:52-59.

78. Stewart, B. A., L. K. Porter, and D. D. Johnson. 1963. Immobilization and mineralization of nitrogen in several organic fractions of soil. Soil Sci. Soc. Amer. Proc. 27:302-304.

79. Stewart, B. A. 1970. A look at agricultural practices in relation to nitrate accumulations. In O. P. Engelstad (ed.) Nutrient mobility in soils: Accumulation and losses. Soil Sci. Soc. Amer. Pub. No. 4, Soil Sci. Soc. Amer., Madison, Wisconsin, pp 47-60.

80. Stewart, B. A., F. G. Viets, Jr., G. L. Hutchinson, and W. D. Kemper. 1967. Nitrate and other water pollutants under fields and feedlots. Environ. Sci. and Tech. 1:736-739.

81. Tabatabai, M. A. and J. M. Bremner. 1970. Use of the Leco automatic 70-second carbon analyzer for total carbon analysis of soils. Soil Sci. Soc. Amer. Proc. 34:608-610.

82. Taylor, A. W. 1967. Phosphorus and water pollution. J. Soil Water Conservation 22:228-231.

83. Udo, E. J., H. L. Bohn, and T. C. Tucker. 1970. Zinc adsorption by calcareous soils. Soil Sci. Soc. Amer. Proc. 34:405-407.

84. Viets, F. G., Jr. 1962. Chemistry and availability of micronutrients in soils. J. Agr. Food Chem. 10:174.

85. Viets, F. G., Jr. and R. C. Hageman. 1971. Factors affecting the accumulation of nitrate in soil, water, and plants. Agriculture Handbook No. 413. Agricultural Research Service, U. S. D. A. 54 pp.

86. Wagner, G. H. and G. E. Smith. 1958. Nitrogen losses from soils fertilized with different nitrogen carriers. Soil Sci. 85:125-129.

87. Wetselaar, R. 1961. Nitrate distribution in tropical soils. I. Possible causes of nitrate accumulation near the surface after a long dry period. Plant and Soil 15:110-120.

88. Wolcott, A. R. 1964. The acidifying effects of nitrogen carriers. Ag. Ammonia News, July-August ed.

89. Wolcott, A. R. and H. D. Foth. 1964. Lime takes the sting out of acid-forming N fertilizers. Crops and Soils, Nov. ed., p. 9.

90. Wolcott, A. R., H. D. Foth, J. C. Schickluna, and J. F. Davis. 1964. Soil reaction key helps select best N fertilizer. Crops and Soils, Jan.-Feb. ed., p. 21.

91. Wolcott, A. R., H. D. Foth, J. F. Davis, and J. C. Schickluna. 1965. Nitrogen carriers: I. Soil effects. Soil Sci. Soc. Amer. Proc. 29:405-410.

92. Yaalon, D. H. 1964. The concentration of ammonia and nitrate in rain water over Israel in relation to environmental factors. Tellus 16:200-204.

APPENDIX

Table 1. Soil NH_4^+-N (ppm) as affected by treatment.

Replication 1

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	48.0	74.9	77.0	95.8	95.7	79.1
5-10	62.6	38.0	87.6	132.8	75.6	103.3
10-15	52.9	46.8	64.7	89.7	79.1	66.6
15-20	40.2	25.6	81.1	84.2	56.9	58.3
20-25	40.2	45.8	132.6	86.4	43.0	56.3
25-30	62.0	30.0	122.5	88.7	47.2	63.8
30-35	28.7	17.6	102.4	85.0	77.0	63.8
35-40	38.0	20.3	74.5	66.5	70.7	76.3
40-45	39.2	18.7	82.9	56.6	72.1	74.2
45-50	30.0	20.3	58.7	71.4	49.9	73.5
50-55	30.4	22.2	49.9	62.6	60.3	68.0
55-60	31.6	16.4	68.3	61.4	58.3	65.9
60-65	26.5	15.0	65.1	64.4	52.7	47.8
65-70	25.6	8.8	50.3	67.9	56.9	48.5
70-75	22.6	6.6	38.2	59.1	36.8	36.1
75-80	22.8	21.8	39.4	63.8	38.8	40.2
80-85	16.8	14.6	48.8	56.8	42.7	29.5
85-90	10.9	1.2	34.9	48.0	29.3	39.8
90-95	13.1	11.5	40.6	50.9	33.4	34.3
95-100	13.9	-	54.2	39.2	26.5	28.7
100-120	10.3	-	24.6	31.4	22.6	27.7
120-140	9.0	2.2	32.2	39.4	21.7	22.2
140-160	8.6	-	21.7	29.6	26.1	18.7
160-180	7.2	-	27.7	18.1	21.3	14.6
180-200	2.0	-	21.5	12.3	22.2	16.4
200-220	1.4	-	21.7	17.0	23.8	18.3
220-240	4.9	-	19.5	20.5	13.1	17.8
240-260	7.0	-	23.2	27.5	13.7	17.9
260-280	4.3	-	17.2	14.4	6.6	17.9
280-300	-	-	20.9	18.7	11.5	20.3
300-320	4.1	2.5	25.6	19.3	13.1	20.1
320-340	4.7	-	25.2	18.1	12.1	24.6
340-360	-	-	17.2	20.7	17.2	19.5
360-380	-	-	21.5	17.8	13.7	20.5
380-400	-	5.5	19.3	22.0	10.0	18.9

Table 1. Soil NH_4^+-N (ppm) as affected by treatment (Cont.)

Replication 1

Depth, cm	19 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	75.6	136.6	95.8	131.8	61.7	75.4
5-10	44.4	43.0	71.4	74.9	61.0	123.5
10-15	59.6	95.0	65.9	70.7	65.2	69.4
15-20	34.7	70.0	83.2	83.2	58.9	84.3
20-25	41.6	74.2	68.7	82.5	51.3	76.3
25-30	47.2	104.0	55.5	73.5	56.9	66.8
30-35	40.9	70.7	68.0	78.4	61.0	98.8
35-40	49.9	78.4	79.7	72.1	70.0	84.8
40-45	31.9	78.4	81.8	86.0	47.2	95.8
45-50	37.4	60.3	56.2	74.2	54.1	117.0
50-55	25.0	59.6	58.9	72.1	54.8	100.9
55-60	25.7	40.2	55.5	88.8	55.5	86.2
60-65	31.8	56.9	50.6	60.3	37.4	64.4
65-70	21.5	45.1	35.4	50.6	44.4	60.4
70-75	17.8	51.3	48.5	48.5	34.7	46.2
75-80	20.5	57.6	42.3	38.1	46.5	59.0
80-85	23.2	34.7	55.2	38.8	28.4	52.4
85-90	16.8	36.1	40.8	37.4	27.7	38.9
90-95	17.4	31.9	44.3	31.2	36.3	44.8
95-100	12.5	36.8	47.0	30.5	30.8	36.0
100-120	10.0	29.3	37.1	22.9	26.7	28.2
120-140	12.3	32.0	41.9	32.6	22.6	40.1
140-160	14.0	30.2	42.7	25.7	23.2	27.5
160-180	10.9	28.5	24.6	22.9	16.8	25.3
180-200	2.9	20.5	27.7	20.7	14.8	32.9
200-220	5.7	20.9	23.8	18.1	12.7	23.0
220-240	7.8	26.5	24.2	18.9	10.0	26.1
240-260	10.0	19.5	40.6	21.3	14.8	21.8
260-280	8.2	18.7	19.3	16.0	15.6	19.2
280-300	12.3	20.0	19.5	23.4	17.4	26.6
300-320	13.9	15.4	17.2	24.0	14.4	34.4
320-340	13.3	15.0	24.6	25.2	18.7	33.2
340-360	12.5	21.7	29.3	19.1	14.6	39.3
360-380	12.1	16.6	18.5	23.4	19.1	24.9
380-400	10.5	11.5	23.4	16.6	15.6	28.4

Table 2. Soil NH_4^+-N (ppm) as affected by treatment.

Depth, cm	Replication 2					
	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	63.7	38.1	84.9	41.7	103.5	174.6
5-10	142.4	52.6	111.6	102.4	124.7	132.5
10-15	113.1	74.9	100.2	78.5	151.2	151.7
15-20	129.1	82.4	79.2	151.9	127.3	152.9
20-25	63.7	98.6	92.7	84.6	170.2	174.2
25-30	56.2	101.4	118.7	98.1	114.7	213.5
30-35	91.0	54.7	72.0	100.5	117.8	160.7
35-40	88.4	73.4	109.3	81.5	96.4	124.4
40-45	84.8	73.2	84.4	111.6	88.8	119.5
45-50	81.8	71.3	46.5	99.8	64.2	111.9
50-55	92.0	57.6	77.9	84.1	73.5	100.2
55-60	73.7	44.6	52.9	48.4	73.0	96.7
60-65	49.5	38.9	69.4	52.6	50.2	87.7
65-70	69.7	50.7	60.2	79.8	61.2	79.6
70-75	73.0	59.3	41.2	75.8	59.9	85.1
75-80	52.6	41.2	71.3	65.2	56.7	120.6
80-85	40.8	52.3	42.4	49.1	63.7	84.4
85-90	50.7	37.0	33.0	54.5	44.6	86.2
90-95	58.3	47.4	37.2	47.1	58.8	78.2
95-100	68.0	52.9	37.4	48.4	35.1	64.4
100-120	43.3	39.8	27.9	52.8	39.1	49.5
120-140	26.1	27.0	39.3	40.8	23.5	36.9
140-160	35.3	24.6	16.6	37.4	22.1	31.8
160-180	21.1	16.3	13.5	30.5	23.0	45.2
180-200	21.8	16.6	15.7	19.7	19.2	25.4
200-220	25.4	19.4	18.3	24.0	13.0	29.6
220-240	19.6	13.3	18.5	21.3	22.0	24.1
240-260	20.9	21.1	20.1	46.2	23.4	25.6
260-280	28.0	18.9	14.0	31.3	19.7	27.5
280-300	22.1	26.3	18.5	36.0	21.3	23.9
300-320	36.0	22.8	17.5	33.4	20.4	20.6
320-340	22.3	15.7	11.6	38.2	15.7	19.7
340-360	19.9	16.8	19.9	33.2	20.6	28.9
360-380	29.8	31.5	14.0	18.3	15.2	29.9
380-400	16.6	19.4	19.2	27.5	15.9	24.6

Table 2. Soil NH_4^+-N (ppm) as affected by treatment (Cont.)

Replication 2

Depth, cm	19 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	137.7	163.5	187.0	129.8	129.9	130.6
5-10	160.5	105.0	149.0	173.4	142.2	119.4
10-15	179.1	133.7	215.6	194.3	152.4	171.3
15-20	137.0	114.2	147.2	120.9	132.4	121.3
20-25	192.2	105.5	259.7	175.4	170.6	110.0
25-30	135.3	129.2	216.4	95.5	180.6	92.7
30-35	202.4	155.0	109.2	64.4	86.3	120.8
35-40	96.9	109.0	150.7	81.0	127.3	96.5
40-45	77.9	125.1	83.2	60.4	81.7	91.9
45-50	87.0	109.7	115.2	81.7	119.7	86.7
50-55	134.4	98.6	70.2	44.8	126.5	63.2
55-60	90.0	74.9	105.7	82.9	109.2	113.5
60-65	93.6	88.8	85.6	55.7	83.4	70.1
65-70	35.3	88.4	84.8	37.0	82.4	64.5
70-75	84.8	85.6	77.9	73.4	74.4	70.1
75-80	82.2	75.6	58.5	50.2	66.4	70.1
80-85	84.4	92.9	58.1	50.0	79.8	50.2
85-90	59.0	119.4	51.2	76.6	77.0	55.2
90-95	53.8	91.3	49.8	41.4	63.2	51.2
95-100	53.6	65.1	53.8	43.1	64.4	49.7
100-120	49.5	41.2	34.4	26.1	46.7	46.5
120-140	47.1	47.6	29.8	41.9	37.5	39.4
140-160	53.3	36.9	27.5	28.4	54.0	21.6
160-180	38.9	23.2	17.5	22.5	25.4	24.4
180-200	41.5	19.9	19.9	26.1	21.1	17.8
200-220	35.5	21.8	23.4	21.1	22.8	21.5
220-240	26.0	20.9	21.5	18.5	20.6	19.9
240-260	28.0	19.9	25.4	29.2	19.7	23.5
260-280	51.6	25.8	18.5	23.0	20.4	20.2
280-300	44.3	21.6	15.9	23.9	26.6	21.3
300-320	43.3	26.0	24.6	19.7	20.6	28.7
320-340	30.3	18.0	18.2	21.9	21.3	22.8
340-360	40.1	19.6	17.5	16.1	23.0	23.4
360-380	33.7	20.8	17.1	21.8	15.4	19.0
380-400	28.0	22.5	15.4	24.6	22.5	18.2

Table 3. Soil NH_4^+-N (ppm) as affected by treatment.

Replication 3

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	123.5	104.8	191.7	69.4	107.3	59.5
5-10	220.4	59.2	156.9	138.8	122.7	79.9
10-15	145.8	149.7	149.1	164.9	131.8	64.5
15-20	138.9	98.4	130.1	68.2	116.8	94.6
20-25	174.0	178.2	142.2	83.9	133.6	101.9
25-30	165.7	116.8	81.8	108.8	130.3	105.0
30-35	174.0	136.2	122.5	78.2	116.1	105.2
35-40	147.6	48.1	100.9	77.0	124.0	95.8
40-45	114.2	84.1	103.1	87.2	84.9	102.2
45-50	141.0	47.2	95.8	93.8	100.7	104.0
50-55	94.8	59.5	88.1	52.1	93.4	63.3
55-60	84.1	64.7	70.9	58.7	84.3	107.6
60-65	85.3	45.0	43.4	54.5	91.7	84.1
65-70	113.8	72.0	47.8	62.6	85.1	48.6
70-75	74.6	42.9	56.7	48.8	62.8	41.5
75-80	73.5	59.2	64.9	63.7	59.3	50.7
80-85	79.9	56.1	56.2	41.7	65.1	47.4
85-90	78.7	52.8	55.9	35.3	47.8	45.5
90-95	70.4	67.8	51.6	36.3	65.1	65.4
95-100	65.4	44.1	55.7	35.8	50.9	47.6
100-120	39.4	44.5	37.7	45.7	38.2	34.1
120-140	40.0	32.0	23.7	36.2	25.8	26.1
140-160	27.9	30.3	28.2	26.6	21.8	24.6
160-180	22.1	32.9	25.4	27.3	22.5	26.8
180-200	24.4	19.7	21.6	25.4	18.9	21.3
200-220	28.7	22.8	19.4	28.4	17.0	15.7
220-240	24.4	13.2	18.7	24.7	18.3	18.7
240-260	20.6	25.4	20.1	37.0	22.7	14.7
260-280	25.4	15.4	20.4	17.8	20.8	18.0
280-300	30.1	16.3	20.6	24.6	19.0	21.5
300-320	35.5	19.2	15.1	29.2	19.0	19.9
320-340	22.3	17.3	22.0	22.1	15.6	22.0
340-360	19.9	14.4	18.3	27.2	17.1	19.7
360-380	17.5	19.6	20.4	37.2	17.0	17.5
380-400	14.7	16.1	14.7	18.2	18.5	28.2

Table 3. Soil NH_4^+-N (ppm) as affected by treatment (Cont.)

	Replication 3					
	19 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	78.4	258.3	50.7	47.8	204.5	170.1
5-10	164.7	212.6	107.6	134.8	214.9	173.0
10-15	81.5	157.3	81.3	100.0	155.2	171.4
15-20	91.3	223.0	97.9	91.0	201.4	125.3
20-25	79.8	161.9	63.2	134.1	191.3	66.1
25-30	111.9	122.0	68.3	145.8	193.4	98.4
30-35	87.4	153.3	73.0	160.4	168.7	66.3
35-40	81.3	176.6	81.7	131.8	165.2	37.4
40-45	89.1	154.9	103.1	91.3	98.6	84.9
45-50	58.1	144.3	85.8	82.4	110.2	75.4
50-55	41.5	139.6	83.9	90.0	66.7	88.9
55-60	37.9	100.3	53.1	77.9	62.3	28.4
60-65	52.8	112.6	61.6	67.0	79.1	53.3
65-70	32.9	101.4	33.6	65.2	68.9	30.5
70-75	38.2	81.8	56.4	59.2	59.3	33.2
75-80	29.8	84.3	53.3	56.2	57.8	36.2
80-85	37.5	67.3	54.7	62.3	59.7	46.2
85-90	73.7	61.2	45.0	49.3	63.5	35.6
90-95	42.0	72.8	54.3	44.1	41.9	55.7
95-100	47.4	68.7	37.4	66.6	56.1	45.0
100-120	37.7	54.2	51.4	40.3	33.2	27.9
120-140	28.0	29.9	26.0	31.1	37.9	32.9
140-160	24.2	29.1	26.0	30.3	33.7	19.6
160-180	23.4	25.4	23.0	23.9	32.5	23.5
180-200	20.1	24.9	16.8	29.4	24.9	18.0
200-220	19.4	23.5	17.3	22.7	27.2	16.6
220-240	20.4	22.3	17.8	20.9	21.5	11.9
240-260	22.8	25.6	19.0	22.7	22.0	26.6
260-280	22.7	27.0	18.0	22.7	24.2	34.8
280-300	19.6	25.3	18.2	23.4	23.7	12.1
300-320	18.5	20.6	14.5	20.1	16.8	14.0
320-340	17.0	19.6	14.7	22.7	21.3	9.2
340-360	18.0	21.1	17.7	23.5	21.2	11.8
360-380	14.7	19.9	15.4	19.2	19.2	13.8
380-400	17.1	17.0	20.2	25.1	15.9	17.0

Table 4. Soil NO_3^--N (ppm) as affected by treatment.

Replication 1

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	3.5	2.5	8.2	7.4	14.4	13.3
5-10	3.5	3.9	7.6	18.1	27.7	27.3
10-15	4.1	-	8.0	16.4	20.9	13.3
15-20	3.7	-	5.5	8.2	9.6	9.8
20-25	2.0	-	5.1	3.3	4.5	5.5
25-30	0.8	-	9.2	4.7	2.0	6.4
30-35	0.6	-	-	2.7	0.9	1.8
35-40	1.6	-	-	7.4	0.4	3.1
40-45	-	-	-	3.3	0.2	4.9
45-50	0.6	-	-	4.3	2.0	6.4
50-55	0.2	-	-	5.7	1.6	7.6
55-60	-	-	-	4.1	1.2	9.0
60-65	-	-	-	1.2	0.6	9.0
65-70	0.2	-	-	6.6	2.0	10.3
70-75	-	-	-	5.1	0.4	10.1
75-80	-	-	-	4.3	2.3	9.2
80-85	-	-	-	2.7	0.6	7.0
85-90	-	-	2.0	5.9	0.6	10.0
90-95	-	-	-	3.3	0.6	9.8
95-100	-	-	-	2.3	-	10.9
100-120	-	-	1.6	2.3	1.2	7.2
120-140	-	-	3.7	4.5	2.2	8.6
140-160	-	-	-	3.7	4.1	5.9
160-180	-	-	-	6.1	4.9	5.3
180-200	-	-	-	4.3	3.7	4.3
200-220	-	-	0.2	4.9	5.5	5.9
220-240	-	-	0.6	5.1	4.3	4.5
240-260	-	-	2.2	6.2	3.7	4.3
260-280	-	-	-	3.7	4.5	3.3
280-300	-	-	1.6	5.9	5.6	4.5
300-320	-	-	0.2	4.3	4.3	4.5
320-340	-	-	3.5	4.3	4.3	5.1
340-360	-	-	0.4	3.5	2.2	4.3
360-380	-	-	1.6	3.1	2.0	5.5
380-400	-	-	0.8	4.1	0.4	4.7

Table 4. Soil NO_3^--N (ppm) as affected by treatment (Cont.)

Replication 1

Depth, cm	19 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	5.1	7.6	6.4	9.6	2.9	10.0
5-10	6.8	10.3	9.2	10.7	15.6	15.9
10-15	5.9	6.8	8.6	11.7	12.1	16.1
15-20	7.8	4.5	5.3	5.7	8.4	12.3
20-25	3.7	3.3	2.9	5.1	3.9	5.2
25-30	4.5	3.7	1.4	3.1	1.8	5.7
30-35	1.0	1.4	2.2	3.5	1.2	7.8
35-40	2.5	2.2	2.0	3.3	2.0	10.0
40-45	2.0	0.8	1.6	4.5	2.2	12.3
45-50	3.5	1.0	1.2	3.9	2.0	13.8
50-55	0.4	1.2	2.5	4.1	1.0	17.0
55-60	0.6	1.8	2.0	3.3	1.4	20.6
60-65	2.3	2.2	2.0	4.7	0.4	16.8
65-70	2.9	3.3	0.2	4.1	1.4	15.2
70-75	1.0	0.4	2.2	3.3	1.8	16.3
75-80	-	1.2	1.6	3.7	0.8	13.0
80-85	2.5	1.0	2.0	3.3	0.4	12.5
85-90	2.7	2.2	-	2.7	0.2	11.8
90-95	1.4	1.0	-	2.9	0.4	13.5
95-100	0.4	1.4	2.2	2.5	-	11.8
100-120	0.2	0.2	2.2	1.8	-	10.6
120-140	3.5	2.2	-	3.9	-	10.9
140-160	4.1	2.7	2.0	3.1	0.4	8.0
160-180	4.7	2.3	2.7	4.9	-	6.9
180-200	1.6	-	3.5	4.1	0.4	6.8
200-220	6.2	0.8	-	3.9	0.2	5.0
220-240	2.7	2.7	1.0	5.1	1.2	5.5
240-260	2.9	1.2	4.1	7.2	1.6	4.8
260-280	3.1	1.4	2.2	3.7	1.6	3.1
280-300	7.8	2.2	1.4	6.4	1.4	3.5
300-320	2.5	1.0	0.2	3.9	1.6	5.9
320-340	6.4	0.6	3.1	4.5	2.2	3.8
340-360	1.8	1.8	3.5	3.5	1.0	4.0
360-380	2.7	1.0	-	2.7	1.4	2.4
380-400	6.4	0.4	-	3.1	0.6	3.5

Table 5. Soil NO_3^--N (ppm) as affected by treatment.

Replication 2

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	4.2	5.2	6.2	8.1	5.5	21.3
5-10	4.3	5.7	8.7	12.6	10.9	24.9
10-15	4.7	5.9	6.1	9.0	10.7	19.0
15-20	3.6	5.4	3.6	9.0	9.2	13.7
20-25	1.9	3.6	6.1	4.0	7.3	10.2
25-30	2.4	2.9	4.0	2.9	3.3	8.1
30-35	1.9	0.4	0.9	2.8	2.8	6.2
35-40	1.9	1.0	0.9	2.3	1.6	3.6
40-45	2.4	1.2	1.4	3.6	1.9	4.7
45-50	1.9	0.7	0.5	3.6	2.8	3.3
50-55	3.3	0.9	2.1	2.6	2.1	3.1
55-60	0.5	1.7	1.2	1.9	2.8	3.5
60-65	0.5	1.7	2.1	2.4	2.8	2.3
65-70	2.4	2.4	-	3.6	0.9	3.1
70-75	3.3	1.9	1.2	2.8	1.9	4.3
75-80	0.7	0.9	1.4	2.1	2.1	4.5
80-85	0.9	1.4	0.2	1.9	2.8	4.5
85-90	2.1	0.5	0.4	1.7	1.7	4.8
90-95	2.4	0.4	-	0.7	1.9	3.5
95-100	2.8	1.2	2.4	1.9	0.7	2.6
100-120	0.4	2.1	-	3.1	0.7	1.0
120-140	1.2	0.5	0.2	1.6	-	1.9
140-160	2.4	-	0.4	1.7	2.6	1.2
160-180	0.2	1.0	0.7	2.1	4.7	2.9
180-200	1.2	1.4	1.7	1.9	4.8	2.9
200-220	1.2	0.9	2.1	2.9	2.8	2.9
220-240	1.6	-	1.9	2.9	4.8	2.4
240-260	2.3	0.5	2.3	3.6	5.7	3.3
260-280	4.2	1.2	1.0	5.2	5.9	4.3
280-300	2.1	2.1	2.4	3.8	5.7	4.2
300-320	3.6	1.7	0.4	4.2	6.1	3.6
320-340	2.1	1.2	-	3.8	5.7	4.2
340-360	3.3	1.7	-	3.8	6.6	3.6
360-380	0.9	2.1	-	2.8	4.5	3.8
380-400	2.3	1.2	2.1	1.9	4.0	3.6

Table 5. Soil NO_3^--N (ppm) as affected by treatment (Cont.)

Replication 2

Depth, cm	19 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	10.2	8.7	10.6	10.9	13.5	16.1
5-10	12.5	9.2	13.2	14.4	16.6	20.2
10-15	9.7	8.1	15.4	15.6	14.0	18.2
15-20	7.3	6.4	10.9	10.0	10.7	10.9
20-25	7.6	4.3	13.3	9.5	7.1	6.6
25-30	5.7	3.8	7.6	3.6	6.1	3.3
30-35	5.4	5.0	4.7	2.9	3.6	5.2
35-40	2.4	4.0	7.1	2.9	4.3	4.2
40-45	2.3	4.2	4.5	1.9	3.8	3.6
45-50	2.9	3.3	4.8	2.9	4.7	3.5
50-55	6.4	2.9	4.5	1.0	5.4	4.7
55-60	3.3	2.4	6.4	4.0	4.5	6.8
60-65	5.4	2.8	4.2	2.3	3.6	3.5
65-70	2.8	3.6	3.5	1.6	3.5	2.8
70-75	4.8	4.3	2.1	1.6	3.6	3.5
75-80	4.7	3.3	3.3	1.9	2.8	2.9
80-85	5.2	4.7	3.1	1.9	3.5	1.7
85-90	2.3	4.8	4.0	3.8	3.5	4.5
90-95	2.8	4.8	3.1	0.7	4.5	2.8
95-100	2.8	5.0	2.4	2.8	4.7	2.4
100-120	4.5	2.4	0.2	-	2.8	2.4
120-140	4.5	1.0	0.5	3.6	2.4	2.1
140-160	2.4	3.3	1.4	3.6	3.8	4.0
160-180	2.4	1.6	0.7	2.3	3.5	5.2
180-200	3.8	2.1	1.0	2.9	3.3	6.9
200-220	2.1	2.9	2.8	2.6	4.2	5.9
220-240	1.9	2.9	2.1	2.3	2.9	5.9
240-260	1.4	1.4	1.9	2.9	4.3	7.1
260-280	4.5	1.6	1.9	2.8	4.2	7.4
280-300	4.2	3.6	2.8	1.2	5.7	8.7
300-320	2.8	2.8	2.8	0.2	4.3	7.8
320-340	2.4	1.2	1.6	2.2	3.8	7.8
340-360	2.9	1.6	1.9	0.2	5.9	7.3
360-380	2.6	1.7	2.8	0.7	3.5	7.6
380-400	1.7	0.7	1.6	2.6	5.4	7.1

Table 6. Soil NO_3^--N (ppm) as affected by treatment.

Replication 3

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	8.5	8.7	11.9	11.6	17.0	14.5
5-10	10.6	7.3	13.0	14.2	20.1	26.0
10-15	8.7	10.7	9.5	14.4	14.5	20.4
15-20	6.4	7.4	6.4	7.8	10.9	12.6
20-25	6.8	4.8	6.2	5.5	10.4	7.4
25-30	4.0	4.8	2.8	5.2	6.1	4.5
30-35	3.5	2.4	4.0	1.9	6.6	5.9
35-40	5.0	1.0	2.6	2.6	7.6	2.9
40-45	3.3	1.4	2.9	3.6	6.2	2.6
45-50	4.0	1.2	3.8	3.5	6.8	3.3
50-55	3.6	1.2	3.5	2.1	6.6	3.5
55-60	3.8	1.7	1.6	2.9	4.8	5.9
60-65	2.6	0.9	0.7	1.7	4.3	6.6
65-70	4.7	1.9	2.1	3.1	9.3	3.5
70-75	3.5	1.7	4.0	2.4	6.9	2.6
75-80	3.5	2.6	3.3	3.1	6.2	4.2
80-85	3.8	2.4	2.8	2.4	7.1	4.7
85-90	2.8	2.8	1.7	0.5	5.2	3.5
90-95	2.6	2.6	2.4	2.3	7.3	4.5
95-100	2.6	1.7	2.8	1.2	6.2	4.8
100-120	1.9	1.9	1.2	2.1	8.7	7.3
120-140	1.6	0.4	0.4	2.3	7.4	6.4
140-160	1.7	2.1	2.1	0.7	8.7	5.7
160-180	0.5	0.9	1.6	1.2	8.1	5.4
180-200	2.1	0.5	2.1	3.1	4.8	7.8
200-220	1.4	0.9	1.7	3.8	4.0	9.3
220-240	1.0	0.9	3.1	2.1	3.3	10.0
240-260	1.4	2.1	3.3	3.8	3.1	9.0
260-280	0.7	1.2	3.6	3.1	3.5	9.7
280-300	1.9	0.4	1.7	3.8	4.2	9.5
300-320	1.7	0.9	1.7	4.0	2.8	9.3
320-340	0.5	1.2	2.1	2.4	3.6	8.7
340-360	0.7	0.7	1.7	3.8	4.0	9.5
360-380	1.6	0.5	0.7	5.7	4.5	6.8
380-400	1.0	0.9	0.5	4.5	3.6	10.7

Table 6. Soil NO_3^--N (ppm) as affected by treatment (Cont.)

Replication 3

Depth, cm	19 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	6.1	6.9	5.5	6.2	9.2	14.4
5-10	8.1	9.5	13.5	10.2	20.2	22.8
10-15	4.2	8.3	13.3	14.7	18.3	17.7
15-20	2.9	11.1	9.3	7.6	11.6	12.3
20-25	1.2	5.7	5.7	6.2	8.1	7.3
25-30	4.0	5.0	2.3	3.4	5.4	5.4
30-35	2.1	2.3	2.6	3.8	4.5	4.2
35-40	2.9	4.0	1.0	2.9	6.8	2.1
40-45	2.1	3.3	2.4	2.9	5.0	2.9
45-50	1.0	3.5	1.7	2.4	3.1	1.7
50-55	1.2	4.5	2.8	2.4	1.9	3.1
55-60	0.5	1.7	1.6	2.4	3.3	0.4
60-65	2.6	3.1	1.0	3.1	1.9	1.2
65-70	1.2	3.5	0.4	2.3	3.3	1.9
70-75	2.3	2.3	2.4	2.9	3.5	3.3
75-80	0.9	2.1	1.0	2.4	3.6	2.8
80-85	3.5	2.3	1.0	1.9	3.1	2.4
85-90	2.8	1.7	1.9	2.6	3.6	3.5
90-95	2.9	3.3	1.6	0.4	2.3	3.1
95-100	4.5	3.5	1.2	2.9	3.3	4.5
100-120	1.7	2.4	1.4	1.0	2.1	2.1
120-140	1.2	0.9	-	1.2	2.1	4.8
140-160	0.7	1.4	-	1.4	3.3	3.6
160-180	0.7	1.7	0.9	0.4	4.0	3.3
180-200	1.7	0.9	0.2	2.4	5.2	3.5
200-220	0.5	0.9	-	1.9	4.2	3.6
220-240	1.0	2.3	0.5	3.8	3.5	3.8
240-260	1.0	2.4	1.4	3.8	3.8	4.3
260-280	1.4	2.4	1.0	4.0	3.6	5.2
280-300	0.5	1.4	4.2	1.6	3.8	4.0
300-320	1.9	0.4	3.6	3.5	3.8	3.1
320-340	0.9	1.4	2.6	2.1	3.1	2.9
340-360	2.1	1.6	1.7	1.6	2.6	3.6
360-380	1.0	1.9	2.8	1.4	2.1	3.3
380-400	0.5	1.2	2.8	2.1	1.4	2.3

Table 7. Total soil N (ppm) as affected by treatment.

Replication 1

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	1170	1190	1070	880	1260	1140
5-10	1100	1050	1100	1020	1060	1100
10-15	1080	1100	1050	810	1020	970
15-20	1070	1070	1010	840	960	970
20-25	1000	1010	1100	820	970	880
25-30	1030	960	1060	800	840	830
30-35	870	950	970	560	880	810
35-40	730	810	880	510	820	860
40-45	750	770	860	540	760	790
45-50	630	730	790	530	640	740
50-55	810	670	1100	540	640	690
55-60	840	500	780	560	630	710
60-65	790	530	760	640	750	570
65-70	710	500	660	650	620	590
70-75	680	480	640	600	650	530
75-80	830	560	610	730	600	570
80-85	800	580	780	620	600	490
85-90	450	500	600	680	520	570
90-95	480	600	690	650	560	500
95-100	570	550	790	580	550	470
100-120	440	420	620	560	480	470
120-140	450	500	640	630	530	470
140-160	470	340	430	520	580	470
160-180	650	400	550	400	470	400
180-200	680	370	500	400	570	430
200-220	660	450	490	420	690	490
220-240	640	360	390	550	450	390
240-260	600	500	470	600	410	430
260-280	670	650	400	540	410	510
280-300	610	570	420	640	510	500
300-320	710	580	580	600	530	530
320-340	780	420	600	640	580	530
340-360	730	460	540	750	530	530
360-380	640	350	500	750	450	570
380-400	770	580	470	710	470	570

Table 7. Total soil N (ppm) as affected by treatment (Cont.)

	Replication 1					
	19 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	1060	980	1160	1250	1220	1060
5-10	1000	830	1050	1070	1120	1180
10-15	960	910	960	1090	1000	1010
15-20	1000	830	960	1070	970	1220
20-25	810	800	950	980	940	1060
25-30	720	820	830	830	940	920
30-35	680	650	800	800	790	850
35-40	660	620	770	760	800	740
40-45	540	820	760	730	660	780
45-50	530	670	770	680	640	800
50-55	480	670	670	720	600	720
55-60	580	570	680	760	640	780
60-65	530	650	600	710	530	580
65-70	460	630	570	630	560	660
70-75	460	610	590	670	500	630
75-80	560	590	560	620	460	520
80-85	500	570	650	580	600	600
85-90	480	510	550	620	400	670
90-95	460	520	550	580	440	580
95-100	420	530	610	520	470	610
100-120	210	500	580	460	470	500
120-140	250	580	670	540	420	610
140-160	240	550	650	560	380	530
160-180	220	610	570	550	420	580
180-200	190	520	550	550	420	600
200-220	130	480	650	570	380	560
220-240	140	570	630	520	300	680
240-260	170	500	550	620	460	610
260-280	210	630	560	500	420	510
280-300	350	610	560	670	500	600
300-320	210	520	630	600	390	600
320-340	300	610	610	680	480	820
340-360	360	850	710	730	480	1120
360-380	310	510	630	650	420	600
380-400	270	410	670	560	480	500

Table 8. Total soil N (ppm) as affected by treatment.

Replication 2

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	1060	1020	1150	1280	1140	1450
5-10	1160	1000	1120	1300	1160	1260
10-15	1180	1090	1130	1040	1220	1160
15-20	940	1080	990	1280	1100	1290
20-25	960	1120	1180	1190	1220	1390
25-30	950	1040	1250	960	970	1310
30-35	900	790	1010	970	1060	1080
35-40	840	940	900	760	870	1080
40-45	860	1000	630	820	820	1000
45-50	840	1150	660	920	540	820
50-55	720	880	540	600	750	860
55-60	580	1200	780	600	760	840
60-65	560	740	840	520	720	780
65-70	780	960	730	700	680	730
70-75	900	1080	690	690	670	900
75-80	600	900	820	680	760	1080
80-85	520	960	610	650	790	1080
85-90	650	740	590	720	850	960
90-95	610	980	600	820	680	740
95-100	770	1210	470	660	660	700
100-120	600	1020	430	660	600	500
120-140	450	900	470	500	580	750
140-160	600	1110	480	470	560	630
160-180	520	530	710	530	500	650
180-200	600	690	580	490	460	580
200-220	480	450	450	370	400	900
220-240	460	630	430	400	540	650
240-260	560	530	750	660	720	590
260-280	740	590	660	520	700	680
280-300	590	510	460	600	630	560
300-320	740	710	670	580	680	680
320-340	620	610	580	800	660	550
340-360	560	790	580	680	620	580
360-380	680	710	580	500	570	840
380-400	570	410	920	640	600	700

Table 8. Total soil N (ppm) as affected by treatment (Cont.)

Depth, cm	Replication 2					
	19 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	1280	1260	1340	1380	1430	1460
5-10	1180	1140	970	1290	1380	1280
10-15	1340	1210	1400	1240	1460	1440
15-20	1300	1150	1550	1450	1440	1260
20-25	1400	1050	1450	1180	1380	1280
25-30	1180	1100	1290	1120	1420	1300
30-35	1090	1100	930	990	1060	1290
35-40	1060	960	890	1020	1100	1160
40-45	780	990	830	730	1000	1000
45-50	790	820	870	810	850	830
50-55	880	960	890	740	960	950
55-60	740	790	790	690	900	940
60-65	730	690	670	800	710	1000
65-70	600	770	830	700	930	860
70-75	900	770	770	840	950	880
75-80	800	960	670	870	830	850
80-85	760	860	630	660	840	760
85-90	660	870	750	750	940	930
90-95	670	880	850	660	760	660
95-100	700	830	720	740	870	900
100-120	580	480	610	650	610	730
120-140	660	520	600	740	620	640
140-160	790	610	630	650	690	620
160-180	680	270	450	510	540	500
180-200	690	350	540	760	680	630
200-220	680	470	590	650	670	620
220-240	610	410	570	620	590	500
240-260	690	580	670	660	520	660
260-280	780	460	530	740	530	550
280-300	780	620	390	870	630	810
300-320	750	710	580	560	620	920
320-340	640	450	560	680	600	600
340-360	830	560	640	720	730	690
360-380	870	650	540	790	580	740
380-400	790	610	610	740	720	720

Table 9. Total soil N (ppm) as affected by treatment.

Replication 3

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	1560	1280	1480	1340	1410	1210
5-10	1670	1110	1310	1280	1300	1080
10-15	1300	1240	1180	1260	1030	1040
15-20	1250	1450	1140	1200	1020	1220
20-25	1390	1210	1180	1160	1060	1080
25-30	1320	1130	1020	1140	1200	1040
30-35	1300	1080	1000	1090	1090	1160
35-40	1330	950	840	1030	1020	1080
40-45	1140	930	750	920	1120	940
45-50	1330	760	900	930	1180	900
50-55	1080	820	820	720	900	940
55-60	1010	930	650	870	850	1000
60-65	950	690	640	900	840	760
65-70	1010	940	600	830	830	450
70-75	890	680	720	740	540	520
75-80	870	890	880	790	680	560
80-85	930	760	720	780	800	630
85-90	880	770	640	740	600	600
90-95	890	900	810	820	900	520
95-100	900	860	760	720	900	540
100-120	610	640	600	860	640	540
120-140	600	570	520	800	510	440
140-160	600	580	590	760	470	550
160-180	1030	620	680	820	520	500
180-200	740	500	620	760	560	480
200-220	600	560	510	710	460	320
220-240	600	460	500	810	500	380
240-260	640	640	500	880	300	480
260-280	680	560	660	690	580	500
280-300	750	580	590	780	530	490
300-320	760	610	570	770	560	560
320-340	630	540	600	530	530	260
340-360	560	580	600	780	570	470
360-380	680	540	560	980	520	500
380-400	550	660	680	990	560	640

Table 9. Total soil N (ppm) as affected by treatment (Cont.)

Replication 3

	19 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	1380	1620	1090	1160	1680	1370
5-10	1230	1430	1310	1170	1350	1320
10-15	1090	1240	1150	1060	1300	1330
15-20	1060	1440	1270	1210	1360	1370
20-25	1090	1270	1060	1230	1270	1070
25-30	910	1480	900	1090	1110	1050
30-35	800	1210	860	1100	1110	990
35-40	780	1150	920	980	1090	670
40-45	810	1020	810	940	910	860
45-50	660	1000	740	760	880	600
50-55	580	940	800	750	790	800
55-60	560	810	700	670	610	640
60-65	660	810	620	400	750	620
65-70	520	770	540	620	570	630
70-75	620	700	660	660	670	510
75-80	510	750	720	590	650	610
80-85	730	650	670	660	810	660
85-90	980	650	600	600	690	580
90-95	620	760	730	620	650	700
95-100	860	690	720	680	780	600
100-120	620	630	600	570	510	520
120-140	440	530	580	460	590	600
140-160	630	530	530	470	520	440
160-180	560	770	420	490	650	490
180-200	600	470	230	510	530	460
200-220	500	480	400	580	590	460
220-240	560	490	440	480	450	520
240-260	480	630	420	540	550	510
260-280	480	620	430	450	540	630
280-300	500	530	460	580	550	400
300-320	540	510	550	640	580	580
320-340	600	470	510	580	490	450
340-360	510	540	480	630	550	400
360-380	480	540	440	660	530	400
380-400	600	540	580	620	450	480

Table 10. Soil pH as affected by treatment.

Replication 1

Depth, cm	0 P, kg/ha					
	N, kg/ha					
	0	45	90	134	179	224
0-5	8.1	8.0	8.0	8.1	8.0	8.0
5-10	8.1	8.0	8.0	8.0	7.9	7.9
10-15	8.0	8.0	7.9	7.9	7.8	7.8
15-20	8.0	7.9	7.9	8.0	7.9	7.9
20-25	8.0	7.9	8.0	8.0	8.0	7.9
25-30	8.1	8.0	8.0	8.0	8.1	8.0
30-35	8.1	8.1	8.1	8.1	8.1	8.1
35-40	8.1	8.0	8.1	8.0	8.2	8.0
40-45	8.1	8.1	8.1	8.1	8.2	8.1
45-50	8.1	8.0	8.1	8.1	8.0	8.1
50-55	8.1	8.1	8.1	8.2	8.2	8.1
55-60	8.1	8.1	8.1	8.1	8.2	8.2
60-65	8.1	8.1	8.1	8.1	8.2	8.1
65-70	8.2	8.1	8.2	8.1	8.1	8.1
70-75	8.2	8.1	8.2	8.1	8.2	8.1
75-80	8.1	8.2	8.2	8.2	8.2	8.2
80-85	8.2	8.1	8.2	8.2	8.2	8.1
85-90	8.2	8.2	8.2	8.2	8.2	8.2
90-95	8.2	8.1	8.2	8.2	8.2	8.2
95-100	8.2	8.1	8.2	8.2	8.2	8.2
100-120	8.2	8.2	8.2	8.2	8.2	8.2
120-140	8.2	8.1	8.2	8.2	8.2	8.2
140-160	8.2	8.2	8.1	8.2	8.2	8.1
160-180	8.2	8.2	8.2	8.2	8.2	8.2
180-200	8.1	8.1	8.2	8.2	8.2	8.2
200-220	8.1	8.2	8.1	8.2	8.2	8.2
220-240	8.1	8.1	8.1	8.2	8.2	8.1
240-260	8.1	8.1	8.1	8.2	8.1	8.2
260-280	8.2	8.2	8.2	8.2	8.1	8.2
280-300	8.2	8.3	8.2	8.2	8.2	8.2
300-320	8.3	8.3	8.2	8.2	8.1	8.2
320-340	8.3	8.3	8.2	8.2	8.3	8.1
340-360	8.4	8.3	8.2	8.2	8.4	8.1
360-380	8.4	8.3	8.2	8.2	8.4	8.2
380-400	8.4	8.2	8.2	8.3	8.5	8.2

Table 10. Soil pH as affected by treatment (Cont.)

	Replication 1					
	19 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	8.1	8.1	8.0	8.0	8.0	8.0
5-10	8.0	7.9	7.9	8.0	7.8	8.0
10-15	8.0	8.0	7.9	7.9	7.8	7.9
15-20	8.0	7.9	8.0	7.9	7.9	7.9
20-25	8.0	7.9	8.0	7.9	8.0	8.0
25-30	8.0	7.9	8.0	8.0	8.0	8.0
30-35	8.1	8.1	8.0	8.1	8.1	8.0
35-40	8.1	8.0	8.1	8.1	8.1	8.0
40-45	8.1	8.2	8.1	8.1	8.0	8.0
45-50	8.2	8.2	8.0	8.1	8.1	8.0
50-55	8.2	8.2	8.1	8.1	8.1	8.0
55-60	8.2	8.2	8.1	8.2	8.1	8.0
60-65	8.2	8.2	8.2	8.1	8.2	8.0
65-70	8.2	8.2	8.2	8.2	8.2	8.0
70-75	8.2	8.2	8.2	8.2	8.1	8.0
75-80	8.2	8.2	8.2	8.2	8.2	8.1
80-85	8.2	8.2	8.2	8.2	8.2	8.1
85-90	8.2	8.2	8.2	8.2	8.2	8.0
90-95	8.2	8.2	8.2	8.2	8.1	8.0
95-100	8.2	8.3	8.2	8.2	8.2	8.0
100-120	8.2	8.2	8.1	8.2	8.2	8.0
120-140	8.2	8.2	8.1	8.2	8.2	8.1
140-160	8.2	8.2	8.1	8.1	8.1	8.1
160-180	8.2	8.1	8.2	8.1	8.2	8.2
180-200	8.2	8.2	8.1	8.1	8.2	8.2
200-220	8.2	8.2	8.1	8.1	8.2	8.2
220-240	8.1	8.1	8.2	8.1	8.1	8.2
240-260	8.2	8.2	8.2	8.1	8.0	8.2
260-280	8.2	8.1	8.2	8.1	8.0	8.1
280-300	8.1	8.1	8.1	8.1	8.1	8.1
300-320	8.3	8.1	8.2	8.1	8.1	8.1
320-340	8.4	8.1	8.1	8.1	8.1	8.1
340-360	8.4	8.2	8.1	8.2	8.1	8.2
360-380	8.4	8.3	8.1	8.3	8.0	8.2
380-400	8.4	8.2	8.1	8.3	8.1	8.3

Table 11. Soil pH as affected by treatment.

	Replication 2					
	0 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	8.0	7.9	7.9	7.9	8.0	8.0
5-10	8.1	7.9	8.0	7.9	7.9	7.9
10-15	8.0	7.9	7.8	7.9	7.9	7.8
15-20	8.0	7.9	7.9	8.0	7.8	7.9
20-25	8.0	8.0	8.0	7.9	7.9	7.9
25-30	8.1	8.0	8.0	8.0	8.0	8.0
30-35	8.1	8.1	8.0	8.1	8.1	8.0
35-40	8.2	8.2	8.1	8.1	8.1	8.0
40-45	8.3	8.1	8.0	8.1	8.1	8.0
45-50	8.2	8.1	8.2	8.2	8.1	8.1
50-55	8.3	8.1	8.1	8.1	8.2	8.1
55-60	8.3	8.1	8.1	8.2	8.2	8.1
60-65	8.3	8.2	8.0	8.2	8.1	8.1
65-70	8.3	8.2	8.1	8.2	8.2	8.2
70-75	8.3	8.1	8.1	8.2	8.2	8.1
75-80	8.3	8.2	8.1	8.2	8.2	8.1
80-85	8.2	8.1	8.1	8.2	8.2	8.1
85-90	8.2	8.1	8.1	8.2	8.2	8.1
90-95	8.3	8.2	8.2	8.2	8.2	8.1
95-100	8.2	8.2	8.1	8.2	8.2	8.1
100-120	8.2	8.1	8.2	8.2	8.2	8.2
120-140	8.3	8.2	8.2	8.2	8.2	8.2
140-160	8.3	8.2	8.2	8.2	8.2	8.2
160-180	8.2	8.2	8.1	8.2	8.2	8.2
180-200	8.2	8.2	8.1	8.2	8.1	8.1
200-220	8.2	8.2	8.1	8.2	8.1	8.1
220-240	8.2	8.2	8.2	8.2	8.1	8.1
240-260	8.2	8.2	8.1	8.2	8.1	8.1
260-280	8.3	8.2	8.0	8.2	8.2	8.1
280-300	8.4	8.1	8.0	8.2	8.1	8.1
300-320	8.4	8.1	8.2	8.1	8.1	8.1
320-340	8.4	8.1	8.3	8.1	8.2	8.1
340-360	8.3	8.2	8.3	8.1	8.3	8.2
360-380	8.4	8.3	8.3	8.1	8.3	8.2
380-400	8.3	8.3	8.4	8.1	8.4	8.2

Table 11. Soil pH as affected by treatment (Cont.)

	Replication 2					
	19 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	8.0	8.0	8.0	8.0	8.0	8.0
5-10	8.0	7.9	7.8	8.0	8.0	8.0
10-15	7.9	7.9	7.9	8.0	8.0	7.9
15-20	7.9	7.9	7.8	7.9	7.9	7.9
20-25	7.9	7.9	7.9	8.0	8.1	7.9
25-30	8.0	7.9	7.9	8.0	8.0	7.9
30-35	8.0	8.0	7.9	8.1	8.1	8.0
35-40	8.1	8.0	8.0	8.1	8.0	8.0
40-45	8.1	8.1	8.1	7.9	8.0	8.1
45-50	8.1	8.1	8.1	8.0	8.0	8.1
50-55	8.1	8.0	8.2	8.0	8.0	8.1
55-60	8.1	8.0	8.2	8.1	8.1	8.1
60-65	8.1	8.1	8.2	8.1	8.0	8.1
65-70	8.1	8.1	8.2	8.2	8.2	8.0
70-75	8.1	8.2	8.2	8.2	8.1	8.1
75-80	8.1	8.1	8.2	8.2	8.2	8.1
80-85	8.1	8.1	8.2	8.2	8.1	8.2
85-90	8.1	8.1	8.2	8.2	8.2	8.1
90-95	8.1	8.1	8.2	8.1	8.2	8.2
95-100	8.1	8.1	8.2	8.1	8.1	8.1
100-120	8.1	8.1	8.2	8.1	8.2	8.2
120-140	8.2	8.1	8.2	8.2	8.2	8.2
140-160	8.1	8.1	8.2	8.1	8.2	8.2
160-180	8.2	8.2	8.2	8.1	8.2	8.2
180-200	8.1	8.2	8.1	8.1	8.2	8.1
200-220	8.1	8.1	8.2	8.1	8.2	8.2
220-240	8.1	8.1	8.2	8.2	8.2	8.2
240-260	8.2	8.1	8.1	8.1	8.2	8.2
260-280	8.1	8.2	8.2	8.1	8.2	8.2
280-300	8.1	8.1	8.2	8.1	8.2	8.2
300-320	8.1	8.1	8.1	8.2	8.2	8.1
320-340	8.1	8.1	8.1	8.2	8.2	8.2
340-360	8.2	8.1	8.3	8.1	8.2	8.2
360-380	8.2	8.1	8.3	8.2	8.2	8.2
380-400	8.3	8.2	8.3	8.0	8.1	8.2

Table 12. Soil pH as affected by treatment.

	Replication 3					
	0 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	8.0	8.1	8.1	8.0	7.9	8.0
5-10	8.1	8.0	8.0	8.0	7.9	8.0
10-15	8.1	8.0	8.0	8.1	7.9	7.9
15-20	8.0	8.0	8.0	7.9	7.9	7.9
20-25	8.1	8.1	8.1	8.0	8.0	8.0
25-30	8.1	8.1	8.1	8.0	8.0	8.1
30-35	8.2	8.1	8.2	8.1	8.0	8.2
35-40	8.1	8.1	8.2	8.1	8.0	8.1
40-45	8.1	8.1	8.3	8.1	8.0	8.1
45-50	8.1	8.1	8.2	8.2	8.0	8.1
50-55	8.1	8.1	8.3	8.1	8.0	8.1
55-60	8.0	8.1	8.3	8.1	8.1	8.2
60-65	8.2	8.1	8.3	8.2	8.1	8.2
65-70	8.2	8.1	8.3	8.2	8.1	8.1
70-75	8.1	8.1	8.2	8.2	8.1	8.1
75-80	8.1	8.2	8.2	8.2	8.1	8.2
80-85	8.2	8.2	8.2	8.2	8.1	8.1
85-90	8.2	8.2	8.3	8.2	8.1	8.2
90-95	8.2	8.2	8.2	8.2	8.1	8.2
95-100	8.2	8.2	8.3	8.2	8.1	8.2
100-120	8.2	8.2	8.3	8.2	8.1	8.2
120-140	8.1	8.2	8.2	8.2	8.1	8.2
140-160	8.2	8.2	8.3	8.2	8.1	8.2
160-180	8.2	8.2	8.3	8.2	8.1	8.2
180-200	8.2	8.2	8.2	8.2	8.1	8.2
200-220	8.2	8.2	8.2	8.2	8.1	8.2
220-240	8.2	8.2	8.3	8.2	8.1	8.2
240-260	8.3	8.2	8.2	8.2	8.1	8.2
260-280	8.2	8.2	8.2	8.2	8.2	8.2
280-300	8.2	8.2	8.2	8.2	8.1	8.1
300-320	8.2	8.2	8.2	8.2	8.2	8.1
320-340	8.3	8.2	8.2	8.2	8.1	8.1
340-360	8.3	8.3	8.3	8.2	8.1	8.2
360-380	8.3	8.3	8.4	8.2	8.1	8.1
380-400	8.3	8.3	8.3	8.2	8.1	8.1

Table 12. Soil pH as affected by treatment (Cont.)

	Replication 3					
	19 P, kg/ha					
	N, kg/ha					
Depth, cm	0	45	90	134	179	224
0-5	8.0	8.2	8.0	8.0	8.1	8.0
5-10	8.1	8.1	8.0	8.1	8.0	8.0
10-15	8.0	7.9	7.9	8.0	8.0	7.9
15-20	8.0	8.0	8.0	8.0	8.0	7.9
20-25	8.0	8.0	8.0	8.0	8.0	7.9
25-30	8.0	8.0	8.0	8.1	8.1	8.0
30-35	8.1	8.0	8.1	8.1	8.1	8.0
35-40	8.2	8.2	8.1	8.1	8.0	8.1
40-45	8.2	8.1	8.1	8.2	8.1	8.1
45-50	8.2	8.0	8.2	8.2	8.1	8.1
50-55	8.2	8.1	8.2	8.3	8.1	8.1
55-60	8.2	8.1	8.2	8.2	8.1	8.2
60-65	8.2	8.1	8.2	8.2	8.2	8.2
65-70	8.2	8.1	8.2	8.2	8.2	8.1
70-75	8.2	8.1	8.2	8.2	8.2	8.2
75-80	8.2	8.2	8.2	8.2	8.2	8.2
80-85	8.2	8.2	8.2	8.2	8.2	8.2
85-90	8.2	8.2	8.2	8.3	8.2	8.2
90-95	8.2	8.2	8.2	8.2	8.2	8.2
95-100	8.2	8.2	8.2	8.3	8.2	8.2
100-120	8.3	8.1	8.2	8.2	8.2	8.2
120-140	8.2	8.1	8.2	8.2	8.2	8.2
140-160	8.2	8.1	8.3	8.2	8.2	8.2
160-180	8.2	8.1	8.3	8.2	8.2	8.2
180-200	8.2	8.1	8.2	8.2	8.2	8.1
200-220	8.2	8.1	8.2	8.2	8.2	8.1
220-240	8.2	8.2	8.2	8.2	8.2	8.2
240-260	8.2	8.0	8.2	8.2	8.2	8.2
260-280	8.2	8.1	8.2	8.2	8.1	8.2
280-300	8.2	8.1	8.3	8.1	8.2	8.2
300-320	8.2	8.1	8.2	8.1	8.2	8.2
320-340	8.2	8.1	8.2	8.2	8.2	8.3
340-360	8.2	8.1	8.2	8.2	8.2	8.4
360-380	8.2	8.2	8.3	8.2	8.3	8.4
380-400	8.3	8.2	8.3	8.2	8.2	8.4

Table 13. Weak Bray extractable soil phosphorus (ppm) as affected by treatment.

Depth,	0 P, kg/ha						19 P, kg/ha					
	N, kg/ha						N, kg/ha					
cm	0	45	90	134	179	224	0	45	90	134	179	224
Rep. 1												
0-5	8.0	9.5	13.5	6.0	6.0	6.5	20.0	26.0	18.5	14.0	20.5	8.0
5-10	7.0	10.0	9.5	4.5	7.0	6.0	10.5	23.5	16.5	10.0	20.0	8.0
10-15	5.5	6.0	5.5	2.5	4.0	4.5	8.5	14.5	8.5	8.0	10.0	8.5
15-20	3.5	2.0	4.0	2.5	3.0	4.5	8.0	9.0	8.5	4.5	12.0	7.0
20-25	2.0	1.0	4.0	1.0	3.5	5.3	1.5	5.0	6.5	3.5	1.5	5.0
25-30	2.0	1.5	4.5	0.8	4.0	6.5	0.5	4.5	3.5	1.0	0.5	1.0
30-35	1.5	1.5	3.5	2.0	1.0	3.0	0.9	2.0	2.5	0.5	0.5	1.0
35-40	0.8	1.0	1.0	0.8	0.5	0.8	1.0	0.5	1.5	0.5	0.5	1.0
Rep. 2												
0-5	9.0	10.0	8.5	6.0	8.5	9.0	37.0	30.5	33.5	20.0	26.5	21.5
5-10	9.5	9.5	5.5	6.0	6.5	6.5	37.0	23.0	29.5	16.5	10.0	17.5
10-15	5.5	4.0	5.0	4.0	5.0	4.5	16.5	17.0	18.5	8.0	8.5	7.0
15-20	4.0	4.5	4.5	4.5	4.5	5.0	24.5	15.0	9.5	7.0	7.0	6.0
20-25	4.0	6.0	4.5	6.0	5.5	4.0	25.5	12.5	8.0	7.0	6.5	5.0
25-30	4.5	2.0	4.0	4.5	2.0	5.0	13.5	2.0	7.5	7.0	3.0	6.0
30-35	8.0	1.0	1.5	2.0	1.5	2.5	4.0	1.0	2.5	3.0	1.5	2.0
35-40	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0
Rep. 3												
0-5	12.0	13.0	9.0	7.5	7.0	10.0	26.5	31.5	24.0	19.0	26.5	17.5
5-10	10.0	7.5	5.0	7.0	6.5	7.0	18.0	27.5	27.5	16.0	17.0	13.0
10-15	6.5	5.0	4.5	5.0	5.0	5.0	11.5	14.0	15.0	9.0	11.0	7.5
15-20	6.0	5.0	4.5	5.0	5.5	5.5	9.5	15.0	9.5	10.0	8.5	8.0
20-25	6.0	5.5	4.5	5.5	5.0	4.5	3.5	12.0	8.0	4.5	6.0	6.5
25-30	4.5	4.5	4.0	3.0	5.5	3.5	0.5	4.0	5.0	2.0	5.0	1.5
30-35	4.0	3.0	2.0	2.5	8.0	1.5	1.0	1.0	2.0	2.0	1.5	1.0
35-40	3.0	2.0	1.5	1.0	3.0	2.5	0.5	2.0	1.0	0.5	0.5	0.5

Table 14. Total soil carbon (%) as affected by fertilizer treatment (kg/ha).

Depth, cm	Replication 1				Replication 2				Replication 3			
	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N
0-5	1.67	1.01	1.47	1.31	0.96	1.20	1.02	1.28	1.09	1.15	1.17	1.12
5-10	1.20	0.97	1.53	1.33	1.09	1.07	1.15	1.18	1.10	1.02	1.10	0.93
10-15	1.60	0.90	1.49	1.38	0.96	1.02	0.99	1.15	1.02	1.00	0.98	1.27
15-20	1.48	0.89	1.53	1.16	0.88	1.02	0.93	0.98	1.04	1.06	0.92	1.08
20-25	1.77	0.82	1.79	1.28	0.89	1.03	1.18	0.93	1.27	1.07	1.41	1.08
25-30	1.98	0.96	2.27	1.65	0.91	1.07	1.32	1.35	1.18	1.15	2.05	1.66
30-35	2.16	1.16	2.18	1.88	1.12	1.54	1.67	1.88	1.23	1.23	2.04	2.12
35-40	1.88	1.88	1.96	2.17	1.88	2.12	2.32	2.03	1.42	1.66	2.03	2.12
40-45	1.66	2.06	2.09	2.08	1.92	2.34	2.37	2.20	1.83	2.04	2.05	2.03
45-50	1.86	2.00	1.62	1.64	2.01	1.95	2.00	2.03	2.06	2.29	1.79	1.95
50-55	1.70	2.03	1.58	1.54	2.03	2.16	1.83	2.04	2.28	2.15	1.71	1.76
55-60	1.49	1.98	1.40	1.75	1.86	1.98	1.71	1.77	2.32	1.83	1.69	1.74
60-65	1.74	1.88	1.33	1.74	1.76	2.07	1.83	1.88	2.19	1.69	1.70	1.87
65-70	1.26	1.78	1.44	1.61	1.71	1.81	1.57	1.92	2.12	1.63	1.58	1.54
70-75	1.28	1.49	1.41	1.29	1.80	1.39	1.30	1.69	1.99	1.66	1.40	1.55
75-80	1.29	1.42	1.37	1.48	1.50	1.24	1.57	1.48	1.89	1.65	1.41	1.23
80-85	1.16	1.51	1.37	1.23	1.38	1.32	1.46	1.32	2.08	1.62	1.29	1.19
85-90	1.23	1.45	1.36	1.38	1.28	1.53	1.53	1.29	1.66	1.49	1.79	1.33
90-95	1.27	1.40	1.23	1.20	1.38	1.57	1.48	1.07	1.40	1.32	1.34	1.40
95-100	1.33	1.47	1.02	1.07	1.18	1.72	1.57	1.23	1.40	1.32	1.29	1.41

Table 15. Soil carbonate-carbon (%) as affected by fertilizer treatment (kg/ha).

	Replication 1				Replication 2				Replication 3			
Depth, cm	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N
0-5	0.96	0.39	0.91	0.65	0.37	0.22	0.26	0.38	0.37	0.28	0.41	0.34
5-10	0.86	0.35	0.98	0.69	0.44	0.39	0.27	0.37	0.42	0.29	0.38	0.37
10-15	0.92	0.34	0.89	0.67	0.40	0.32	0.33	0.34	0.42	0.26	0.36	0.52
15-20	1.08	0.33	0.92	0.55	0.38	0.29	0.24	0.36	0.46	0.28	0.45	0.31
20-25	1.29	0.49	1.48	0.75	0.33	0.38	0.31	0.37	0.62	0.57	0.88	0.54
25-30	1.61	0.68	1.84	1.11	0.44	0.56	0.75	0.78	0.71	0.67	1.59	1.32
30-35	1.78	0.96	1.76	1.42	0.77	0.98	1.21	1.37	0.80	0.79	1.73	1.74
35-40	1.67	1.48	1.68	1.91	1.47	1.57	1.57	1.68	1.04	1.12	1.76	1.81
40-45	1.63	1.71	1.68	1.84	1.53	1.85	1.69	1.76	1.35	1.47	1.68	1.81
45-50	1.62	1.80	1.59	1.59	1.72	1.92	1.64	1.80	1.62	1.81	1.63	1.81
50-55	1.51	1.82	1.53	1.41	1.73	1.80	1.47	1.68	1.85	1.74	1.57	1.69
55-60	1.46	1.85	1.29	1.63	1.63	1.70	1.49	1.57	1.89	1.48	1.57	1.64
60-65	1.43	1.72	1.31	1.55	1.58	1.74	1.43	1.55	1.82	1.43	1.50	1.65
65-70	1.03	1.53	1.43	1.45	1.55	1.52	1.19	1.69	1.78	1.39	1.37	1.54
70-75	1.23	1.52	1.37	1.43	1.59	0.99	1.36	1.34	1.79	1.39	1.33	1.47
75-80	1.21	1.44	1.27	1.39	1.38	0.87	1.36	1.39	1.78	1.46	1.25	1.22
80-85	1.27	1.40	1.28	1.31	1.29	0.91	1.14	1.37	1.80	1.43	1.49	1.35
85-90	1.29	1.40	1.24	1.25	1.21	1.18	1.19	1.27	1.54	1.30	1.39	1.19
90-95	1.30	1.31	1.23	1.25	1.24	1.35	1.22	1.22	1.32	1.11	1.25	1.30
95-100	1.30	1.30	1.19	1.18	1.12	1.33	1.19	1.15	1.27	1.11	1.25	1.31

Table 16. Soil organic carbon (%) as affected by fertilizer treatment (kg/ha).

Depth, cm	Replication 1				Replication 2				Replication 3			
	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N	0 P 0 N	0 P 224 N	19 P 0 N	19 P 224 N
0-5	0.71	0.62	0.56	0.66	0.59	0.98	0.76	0.90	0.72	0.87	0.76	0.78
5-10	0.34	0.62	0.55	0.64	0.65	0.68	0.88	0.81	0.68	0.73	0.72	0.56
10-15	0.68	0.56	0.60	0.71	0.55	0.70	0.66	0.81	0.60	0.74	0.62	0.75
15-20	0.40	0.56	0.61	0.61	0.50	0.73	0.69	0.62	0.58	0.78	0.47	0.77
20-25	0.48	0.33	0.31	0.53	0.56	0.65	0.87	0.56	0.65	0.50	0.53	0.54
25-30	0.37	0.28	0.43	0.54	0.47	0.51	0.57	0.57	0.47	0.48	0.46	0.34
30-35	0.38	0.20	0.42	0.46	0.35	0.56	0.46	0.51	0.43	0.44	0.31	0.38
35-40	0.21	0.40	0.28	0.26	0.41	0.55	0.75	0.35	0.38	0.54	0.27	0.31
40-45	0.03	0.35	0.41	0.24	0.39	0.49	0.68	0.44	0.48	0.57	0.37	0.22
45-50	0.24	0.20	0.03	0.05	0.29	0.03	0.36	0.23	0.44	0.48	0.16	0.14
50-55	0.19	0.21	0.05	0.13	0.30	0.36	0.36	0.36	0.43	0.41	0.14	0.07
55-60	0.03	0.13	0.11	0.12	0.23	0.28	0.22	0.20	0.43	0.35	0.12	0.20
60-65	0.31	0.16	0.02	0.19	0.18	0.33	0.40	0.33	0.37	0.26	0.20	0.22
65-70	0.23	0.25	0.01	0.16	0.16	0.29	0.38	0.22	0.34	0.24	0.21	0.00
70-75	0.05	0.00	0.04	0.00	0.21	0.36	0.00	0.20	0.20	0.27	0.07	0.08
75-80	0.08	0.00	0.10	0.09	0.12	0.34	0.21	0.09	0.11	0.19	0.16	0.01
80-85	0.00	0.11	0.09	0.00	0.09	0.41	0.32	0.00	0.28	0.19	0.00	0.00
85-90	0.00	0.05	0.12	0.13	0.07	0.35	0.34	0.02	0.12	0.19	0.40	0.14
90-95	0.00	0.09	0.00	0.00	0.14	0.22	0.25	0.00	0.08	0.21	0.09	0.10
95-100	0.03	0.17	0.00	0.00	0.06	0.39	0.38	0.08	0.13	0.21	0.04	0.10

Table 17. Soil cation exchange capacity (meq/100 g) as affected by treatment.

	Replication 1					
	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
Depth, cm	0	134	224	0	134	224
0-5	22.7	22.0	22.2	22.0	23.9	23.9
5-10	22.5	22.1	22.9	22.3	23.6	23.9
10-15	21.5	23.7	22.6	23.2	24.3	25.4
15-20	22.5	22.7	22.1	22.9	23.9	25.2
20-25	21.7	21.8	22.6	22.0	23.6	23.9
25-30	21.4	21.2	23.6	21.4	21.8	22.5
30-35	20.9	20.7	22.9	21.8	21.4	21.8
35-40	21.1	21.2	22.0	21.8	21.1	21.1
40-45	20.7	21.1	21.6	21.4	21.1	21.4
45-50	20.5	20.9	21.5	20.7	21.1	21.4
50-55	20.6	20.2	21.3	20.7	21.4	21.1
55-60	20.3	20.5	20.1	21.2	21.1	21.1
60-65	20.6	20.5	21.3	20.9	20.9	21.1
65-70	21.0	20.9	21.7	20.7	20.5	21.4
70-75	21.1	20.5	22.1	21.1	21.1	21.1
75-80	22.7	21.1	21.9	21.1	21.1	21.4
80-85	20.7	21.1	21.6	21.2	21.4	21.4
85-90	20.3	21.4	21.2	21.4	21.8	21.4
90-95	20.7	21.4	21.8	21.4	21.4	22.1
95-100	21.1	22.0	21.5	21.6	21.1	22.0

Table 18. Soil cation exchange capacity (meq/100 g) as affected by treatment.

	Replication 2					
	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
Depth, cm	0	134	224	0	134	224
0-5	24.3	24.1	23.6	22.6	23.2	23.6
5-10	25.0	24.1	23.6	22.5	23.7	23.9
10-15	25.7	23.6	22.9	23.6	23.6	23.7
15-20	25.4	23.2	23.2	22.0	23.6	23.9
20-25	24.6	25.3	22.9	23.5	23.9	25.4
25-30	25.2	23.7	25.4	25.0	24.3	25.0
30-35	26.2	21.8	24.3	23.9	22.9	23.2
35-40	23.6	21.5	22.5	21.9	21.8	21.8
40-45	22.5	20.6	21.6	21.5	21.4	21.4
45-50	22.0	21.4	21.2	21.3	21.4	21.4
50-55	22.1	21.4	21.5	20.8	21.6	21.2
55-60	22.1	21.5	21.2	21.6	21.2	21.2
60-65	22.1	21.0	21.1	20.8	21.2	21.4
65-70	22.1	21.4	20.9	21.4	21.3	21.1
70-75	21.4	21.4	20.6	21.2	20.5	20.9
75-80	22.5	20.8	20.8	21.0	20.8	21.4
80-85	22.1	20.3	21.0	21.4	20.1	21.4
85-90	21.6	20.8	21.0	21.1	20.0	21.2
90-95	22.0	21.2	21.2	21.4	21.2	21.3
95-100	22.0	21.2	21.0	21.4	20.2	21.5

Table 19. Soil cation exchange capacity (meq/100 g) as affected by treatment.

	Replication 3					
	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
Depth, cm	0	134	224	0	134	224
0-5	23.5	24.3	22.9	22.1	23.4	23.7
5-10	23.8	23.9	22.7	22.6	22.8	23.5
10-15	23.5	23.6	22.5	23.8	22.8	24.8
15-20	23.6	23.9	23.2	22.5	21.8	22.4
20-25	24.0	25.0	23.2	23.6	22.9	24.3
25-30	23.3	25.0	23.6	24.7	23.8	24.5
30-35	23.1	23.2	23.6	24.2	23.1	21.9
35-40	22.7	21.8	23.9	22.3	21.9	24.3
40-45	22.3	21.4	22.9	21.5	21.2	21.2
45-50	21.6	21.4	21.8	20.8	20.7	21.1
50-55	21.8	21.4	22.0	21.2	20.9	21.3
55-60	22.0	21.4	21.6	20.5	20.5	21.1
60-65	21.4	21.1	21.4	21.1	20.6	21.0
65-70	21.5	21.4	21.4	20.7	20.1	21.8
70-75	21.4	20.5	21.1	21.3	20.3	21.4
75-80	21.9	20.4	21.2	21.4	20.5	21.1
80-85	20.9	20.7	21.6	20.9	19.9	21.2
85-90	19.9	20.0	21.5	21.2	19.9	21.2
90-95	21.4	20.4	21.7	21.3	20.1	21.7
95-100	21.5	20.0	21.5	21.2	20.0	21.9

Table 20. Extractable soil calcium (ppm) as affected by treatment--replication 1.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	17943	15199	06352	16059	15106	12122
5-10	15880	16077	06297	16674	15279	13311
10-15	17375	18208	05223	16547	14319	12962
15-20	20342	17703	05458	15312	16824	10408
20-25	19864	18423	09593	17366	16038	13014
25-30	18205	17832	12071	15939	17704	19719
30-35	16445	13002	17551	14607	17328	15535
35-40	19995	18755	14680	16049	17448	08652
40-45	17172	18084	13051	17977	19402	09180
45-50	15541	17329	16177	15179	18010	11505
50-55	16532	18050	13263	19460	18666	13997
55-60	17168	16873	14634	11383	18184	12204
60-65	17410	16898	16922	14768	16204	14136
65-70	15328	18884	18554	15401	18709	12539
70-75	16198	17546	18747	16601	17019	14333
75-80	15372	16785	18210	12723	17104	17801
80-85	16021	18260	18355	14358	16179	17189
85-90	16408	16887	16414	14374	16089	17480
90-95	18884	15872	16877	15224	17046	16544
95-100	17522	14587	17442	16072	17868	16386

Table 21. Extractable soil calcium (ppm) as affected by treatment--replication 2.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	06230	06000	04987	05409	05620	05960
5-10	07282	06530	05113	05337	05185	05652
10-15	06100	06590	04555	06460	04377	04869
15-20	05903	05276	04555	04787	05680	04752
20-25	05159	07371	04621	06558	04960	05593
25-30	07846	17264	09943	16736	14573	14591
30-35	15411	19993	18538	19614	20647	21136
35-40	22854	18704	18932	16935	18074	16736
40-45	18198	16569	12427	14351	14107	17068
45-50	16407	16971	13658	13228	16669	16724
50-55	16607	15000	16742	16266	19676	17324
55-60	17975	14182	19015	26106	20827	18043
60-65	20035	17804	20029	20061	21517	19705
65-70	18740	22129	21323	14562	21589	14844
70-75	18291	18049	16528	13126	20546	20109
75-80	19199	19244	14972	16913	21555	20174
80-85	17779	20312	15665	16699	19749	19629
85-90	17558	20124	18345	12384	19459	17934
90-95	16797	19462	18937	18871	19834	18612
95-100	17640	19814	18262	14594	18437	16947

Table 22. Extractable soil calcium (ppm) as affected by treatment--replication 3.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	07741	06002	07209	06374	07638	05642
5-10	07431	06075	06741	05845	07203	05566
10-15	07585	05050	06490	05498	06636	07724
15-20	08855	05710	08355	07579	07548	04523
20-25	13803	10197	15953	18488	14339	09435
25-30	16285	11632	17742	20525	17438	19009
30-35	17352	13727	19881	17663	22716	20745
35-40	21433	15400	23689	16681	18520	17467
40-45	21863	12183	17359	16370	22772	20557
45-50	12840	12059	12511	16265	20291	16260
50-55	10801	15391	12785	17913	20841	16952
55-60	14751	16179	18229	19773	25259	20594
60-65	12823	19090	21415	19839	25223	19023
65-70	13376	20617	20806	20878	24623	21588
70-75	14960	18362	19769	21244	20689	20353
75-80	16327	14919	17248	19325	26478	17937
80-85	17443	19667	18574	16698	20832	17964
85-90	18673	14812	18396	19968	21380	14470
90-95	19221	16502	17214	18016	09658	21880
95-100	17725	17617	17017	15909	11223	21753

Table 23. Extractable soil magnesium (ppm) as affected by treatment--replication 1.

	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
Depth, cm	0	134	224	0	134	224
0-5	683	599	477	632	583	536
5-10	645	662	510	618	569	513
10-15	684	659	472	609	564	513
15-20	708	625	472	581	595	476
20-25	689	671	540	594	583	512
25-30	710	660	596	652	617	557
30-35	722	648	711	667	599	546
35-40	847	723	729	731	606	509
40-45	775	758	680	786	663	509
45-50	761	755	737	747	672	614
50-55	811	758	807	854	749	658
55-60	839	804	784	839	763	692
60-65	871	810	833	860	739	758
65-70	829	883	883	863	792	788
70-75	930	873	806	887	837	803
75-80	893	869	940	873	841	813
80-85	868	862	985	868	864	828
85-90	945	889	900	889	906	833
90-95	1023	887	961	877	900	833
95-100	910	847	1002	839	879	817

Table 24. Extractable soil magnesium (ppm) as affected by treatment--replication 2.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	530	547	514	515	500	510
5-10	519	547	473	505	467	497
10-15	510	552	441	509	472	445
15-20	498	486	427	466	469	462
20-25	525	527	445	507	504	513
25-30	571	610	504	692	590	591
30-35	685	589	568	734	617	576
35-40	731	581	531	692	569	530
40-45	669	570	461	682	574	530
45-50	678	634	504	696	601	568
50-55	678	616	535	725	647	575
55-60	778	682	572	827	703	597
60-65	803	730	604	806	762	648
65-70	787	814	719	685	773	604
70-75	789	824	701	792	805	686
75-80	863	816	664	816	859	747
80-85	816	876	705	825	860	779
85-90	827	877	730	785	876	825
90-95	777	896	756	851	887	841
95-100	783	888	756	856	882	913

Table 25. Extractable soil magnesium (ppm) as affected by treatment--replication 3.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	519	500	514	571	530	436
5-10	498	467	481	526	467	512
10-15	486	428	477	530	453	533
15-20	482	433	504	574	470	430
20-25	529	547	608	731	603	542
25-30	585	648	636	682	641	690
30-35	614	608	665	696	722	646
35-40	664	577	751	675	598	634
40-45	709	599	681	715	720	658
45-50	644	641	624	796	743	696
50-55	653	702	676	835	812	720
55-60	721	742	772	853	803	782
60-65	712	795	812	847	964	831
65-70	763	842	832	861	870	925
70-75	805	834	826	907	832	914
75-80	831	883	834	898	1061	879
80-85	775	887	882	871	942	935
85-90	860	856	874	797	926	890
90-95	873	876	884	858	905	910
95-100	864	881	883	866	848	895

Table 26. Extractable soil sodium (ppm) as affected by treatment--replication 1.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	140	58	82	87	58	105
5-10	121	101	150	48	58	90
10-15	140	58	97	58	39	82
15-20	87	48	63	39	53	82
20-25	174	63	101	72	39	75
25-30	130	80	68	63	68	90
30-35	169	72	106	87	58	97
35-40	106	87	125	72	53	112
40-45	203	63	174	77	53	105
45-50	121	92	145	63	63	105
50-55	111	80	125	58	58	60
55-60	116	72	125	48	82	105
60-65	97	87	135	68	87	105
65-70	135	53	111	77	97	105
70-75	121	80	101	53	106	112
75-80	111	77	130	72	63	105
80-85	121	68	111	72	53	120
85-90	188	68	135	53	77	112
90-95	174	77	135	58	58	97
95-100	159	58	116	68	77	120

Table 27. Extractable soil sodium (ppm) as affected by treatment--replication 2.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	82	106	82	92	72	105
5-10	90	135	82	125	92	97
10-15	82	154	67	111	72	105
15-20	52	97	67	106	72	75
20-25	75	106	75	82	68	90
25-30	75	82	67	135	58	105
30-35	105	92	60	140	77	105
35-40	82	125	112	135	68	97
40-45	112	101	90	92	106	127
45-50	120	145	82	92	63	120
50-55	105	106	97	140	67	105
55-60	75	121	90	116	67	105
60-65	112	101	112	97	67	97
65-70	105	130	82	97	60	112
70-75	97	130	90	130	67	90
75-80	82	135	75	101	67	75
80-85	97	97	75	92	67	75
85-90	112	111	97	111	67	67
90-95	112	106	97	87	67	67
95-100	90	145	112	97	67	67

Table 28. Extractable soil sodium (ppm) as affected by treatment--replication 3.

Depth,	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
cm	0	134	224	0	134	224
0-5	60	63	97	45	97	97
5-10	60	53	75	52	130	87
10-15	45	39	67	37	83	87
15-20	45	39	75	37	83	68
20-25	60	53	90	52	121	68
25-30	60	72	105	67	106	87
30-35	60	58	75	67	145	85
35-40	60	63	97	67	87	82
40-45	67	53	112	67	100	97
45-50	82	92	97	67	134	101
50-55	75	72	75	60	121	130
55-60	82	53	90	67	116	135
60-65	75	77	105	67	101	101
65-70	82	72	90	67	145	100
70-75	82	39	75	60	139	106
75-80	82	58	60	60	106	97
80-85	82	72	60	60	135	77
85-90	82	87	60	67	101	100
90-95	75	97	60	67	87	100
95-100	75	92	60	67	82	100

Table 29. Extractable soil potassium (ppm) as affected by treatment--replication 1.

Depth,	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
cm	0	134	224	0	134	224
0-5	545	534	612	534	612	511
5-10	523	523	567	490	556	524
10-15	556	445	478	490	490	524
15-20	512	423	501	467	501	460
20-25	467	412	478	434	467	422
25-30	456	412	456	423	423	396
30-35	456	423	445	445	401	358
35-40	501	456	367	456	423	345
40-45	456	478	367	490	423	358
45-50	467	478	378	478	445	358
50-55	523	490	389	533	490	383
55-60	556	523	423	567	534	422
60-65	579	579	434	601	556	460
65-70	601	623	534	634	556	498
70-75	668	601	545	668	623	498
75-80	712	612	590	723	679	588
80-85	701	645	668	768	723	664
85-90	690	690	723	801	779	728
90-95	790	745	757	823	834	767
95-100	712	757	823	857	834	830

Table 30. Extractable soil potassium (ppm) as affected by treatment--replication 2.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	524	656	549	623	690	537
5-10	575	634	473	612	590	575
10-15	511	623	485	567	556	498
15-20	511	545	460	567	534	511
20-25	498	567	460	590	579	524
25-30	524	523	498	623	545	485
30-35	524	490	473	590	523	447
35-40	473	467	422	534	478	422
40-45	460	445	409	523	478	409
45-50	485	445	473	534	467	409
50-55	498	423	434	523	473	409
55-60	537	456	460	567	485	409
60-65	562	467	460	579	485	396
65-70	600	512	473	857	511	383
70-75	664	567	549	590	537	460
75-80	779	601	549	634	575	485
80-85	792	634	600	668	600	511
85-90	856	679	588	701	626	562
90-95	881	712	639	745	652	588
95-100	920	768	652	801	677	626

Table 31. Extractable soil potassium (ppm) as affected by treatment--replication 3.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
0-5	562	590	652	588	668	701
5-10	537	567	613	511	645	612
10-15	511	545	549	460	556	612
15-20	524	523	498	460	567	623
20-25	498	567	485	473	579	601
25-30	498	523	460	422	501	567
30-35	498	445	460	383	478	512
35-40	434	389	434	383	356	490
40-45	409	367	396	383	389	456
45-50	383	378	370	434	423	467
50-55	370	401	383	460	389	467
55-60	383	434	396	485	434	478
60-65	422	501	396	537	534	579
65-70	460	556	447	600	501	601
70-75	498	579	460	664	556	590
75-80	537	668	485	652	701	623
80-85	549	701	511	677	668	701
85-90	588	745	537	562	712	746
90-95	639	801	588	728	779	751
95-100	690	857	613	754	779	800

Table 32. DTPA-extractable soil copper (ppm) as affected by treatment.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
Rep. 1						
0-10	.59	.54	.65	.80	.65	.65
10-20	.69	.80	.59	.78	.73	.67
20-30	.80	.80	.67	.78	.73	.73
30-40	.67	.73	.67	.65	.62	.67
40-50	.62	.65	.59	.65	.56	.65
Rep. 2						
0-10	.65	.73	.69	.69	.62	.67
10-20	.65	.69	.65	.73	.73	.67
20-30	.62	.78	.67	.80	.73	.86
30-40	.75	.80	.75	.84	.84	.78
40-50	.67	.75	.75	.67	.78	.65
Rep. 3						
0-10	.62	.62	.56	.56	.59	.59
10-20	.65	.62	.56	.48	.62	.59
20-30	.65	.75	.59	.67	.69	.51
30-40	.73	.78	.69	.45	.69	.56
40-50	.75	.67	.67	.48	.62	.56

Table 33. DTPA-extractable soil iron (ppm) as affected by treatment.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
Rep. 1						
0-10	4.98	6.07	4.82	5.39	5.32	5.64
10-20	4.82	6.07	3.33	5.39	5.82	5.64
20-30	4.82	5.98	3.67	3.49	4.48	4.64
30-40	3.90	4.57	2.78	3.49	3.42	3.58
40-50	3.90	4.06	2.61	3.01	2.94	3.42
Rep. 2						
0-10	3.74	7.00	5.39	5.64	7.68	6.32
10-20	3.33	6.32	6.23	6.07	7.59	6.32
20-30	3.33	5.39	5.48	5.23	6.39	4.82
30-40	2.69	4.23	3.83	3.83	3.99	3.90
40-50	1.97	4.15	3.33	3.83	4.48	3.26
Rep. 3						
0-10	4.40	5.82	4.40	3.99	5.89	6.14
10-20	4.57	5.39	4.48	3.17	4.82	5.98
20-30	3.83	4.06	3.90	3.42	4.89	3.58
30-40	4.15	4.06	3.67	2.45	3.99	3.26
40-50	3.83	3.74	3.26	2.94	3.42	3.42

Table 34. DTPA-extractable soil manganese (ppm) as affected by treatment.

Depth, cm	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
	0	134	224	0	134	224
Rep. 1						
0-10	9.68	12.29	16.17	9.46	10.78	9.60
10-20	8.45	8.96	13.73	7.11	8.08	8.62
20-30	7.23	8.96	8.83	5.48	5.11	7.15
30-40	4.51	6.02	5.18	3.86	4.11	4.88
40-50	4.25	6.40	4.03	3.29	4.00	4.33
Rep. 2						
0-10	16.12	14.37	15.96	14.12	14.02	15.28
10-20	11.09	11.41	12.57	12.52	12.66	12.57
20-30	10.96	6.05	10.60	8.83	6.91	8.91
30-40	6.51	4.55	6.02	5.63	5.36	5.74
40-50	5.78	3.54	4.00	4.22	3.64	5.55
Rep. 3						
0-10	12.52	10.78	17.25	10.86	12.33	12.95
10-20	9.16	9.60	10.16	6.99	9.64	9.64
20-30	6.79	6.79	6.24	4.25	5.55	4.73
30-40	4.77	3.75	4.73	3.68	4.25	2.90
40-50	4.18	3.64	3.46	3.11	3.15	2.90

Table 35. DTPA-extractable soil zinc (ppm) as affected by treatment.

	0 P, kg/ha			19 P, kg/ha		
	N, kg/ha			N, kg/ha		
Depth, cm	0	134	224	0	134	224
Rep. 1						
0-10	1.53	1.68	1.74	1.42	1.51	1.23
10-20	2.25	1.17	1.75	2.07	1.57	2.11
20-30	0.66	2.18	0.42	0.63	0.30	0.47
30-40	0.24	0.17	0.13	0.10	0.09	0.21
40-50	0.20	0.17	0.11	0.12	0.07	0.08
Rep. 2						
0-10	1.69	1.47	1.69	1.63	2.05	2.03
10-20	0.90	0.95	2.81	3.13	3.35	1.27
20-30	0.76	0.22	0.93	2.39	0.92	0.24
30-40	0.25	0.13	0.08	0.17	0.15	0.16
40-50	0.12	0.09	0.04	0.17	0.16	0.44
Rep. 3						
0-10	2.40	2.56	2.14	1.64	2.98	1.69
10-20	3.40	4.57	0.53	1.04	2.42	1.90
20-30	1.11	0.40	0.34	0.34	0.46	0.55
30-40	0.17	0.12	0.08	0.07	0.27	0.00
40-50	0.20	0.10	0.04	0.07	0.14	0.00

EFFECTS OF CONTINUED APPLICATION OF NITROGEN AND PHOSPHORUS ON THE CHEMICAL COMPOSITION OF IRRIGATED RICHFIELD SILT LOAM

by

GALEN RAY NIEDENTHAL

B. S., Kansas State University, 1969

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY

1974

This investigation, part of a long-range study initiated at the Tribune Branch Experiment Station in 1961 to evaluate the response of irrigated corn to various rates of fertilizers, was concerned with the effect of continuous applications of nitrogen and phosphorus on the chemical properties of the Richfield silt loam soil, and to determine the fate of applied nitrogen not utilized by the corn crop. Soil core samples were taken in January and February of 1972 to a depth of 4 meters and analyzed for several soil constituents.

Ammonium-nitrogen accumulation in the soil was high, exceeding 200 ppm in some samples near the soil surface. There was a significant (0.05) decrease in ammonium-nitrogen with depth. Ammonium-nitrogen was significantly increased by the addition of 19 kg P/ha, but the increase due to applied nitrogen was not significant.

Soil nitrate-nitrogen concentrations were much lower than ammonium-nitrogen levels, rarely exceeding 25 ppm. Nitrate-nitrogen decreased with depth, and there were no noticeable peaks of nitrate accumulation in the profile. Nitrogen and phosphorus treatments increased the amount of nitrate-nitrogen in the soil as fertilizer rates increased.

Total soil nitrogen, excluding nitrate-nitrogen, decreased with depth. Nitrogen applications had no measurable effect on total soil nitrogen, but the addition of 19 kg P/ha significantly decreased total soil nitrogen.

Both nitrogen and phosphorus significantly lowered soil pH, even though measured differences were small. Soil pH increased with depth, ranging from approximately 7.9 near the surface to 8.3 at the 400 cm depth.

Weak Bray extractable phosphorus decreased as nitrogen rates increased, and increased markedly when 19 kg P/ha were applied. There was a marked decrease in available phosphorus with depth.

High rates of nitrogen fertilizer tend to decrease extractable calcium and magnesium in this soil. Phosphorus had no significant effect on calcium and magnesium. Extractable sodium content was increased by nitrogen fertilization when phosphorus was applied. Sodium concentration decreased when phosphorus was applied by itself. Sodium concentration in the profile varied quite erratically and was not affected by depth.

Extractable soil potassium content decreased when increasing nitrogen rates were applied. Addition of 19 kg P/ha produced an increase in extractable soil potassium. Potassium levels were quite high, explaining the lack of crop response to applied potassium at the experimental site.

Soil cation exchange capacity, ranging from 20-25 meq/100 g, was not significantly affected by nitrogen or phosphorus treatments. Soil cation exchange capacity decreased with depth.

Levels of all micronutrients seemed to be adequate in the upper 15 cm of soil. Iron, manganese, and zinc decreased with depth, but copper had a zone of highest concentration at the 25-35 cm depth. Phosphorus had a significant effect only on manganese concentration, causing a decrease in DTPA-extractable manganese. Conversely, nitrogen applications led to an increase in soil extractable manganese.

Nitrogen and phosphorus had inverse effects on all forms of soil carbon, but measurable effects were quite small and usually insignificant. Carbonate-carbon comprised from 75-80% of the total soil carbon when averaged across all depths.