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INFLUENCE OF VARIOUS NITROGEN SOURCES ON SOIL PHYSICAL
AND CHEMICAL PROPERTIES

by

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B.S., Department of Soil Science
KASETSART UNIVERSITY, THAILAND, 1977

A MASTER'S THESIS

submitted in partial fulfillment of the
requirement for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

Approved by :

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ACKNOWLEDGEMENT

I wish to express sincere thanks and appreciation to my Major Professor, Dr. L. R. Stone, Associate Professor of Soil Physics, for his supervision, guidance, and indispensable help throughout this study.

I also wish to express my appreciation to Dr. R. Ellis, Jr., and Dr. D. A. Whitney for their serving on my committee. Many thanks are due to Dr. D. A. Whitney for soil chemical analyses and data, and to Dr. D. E. Johnson for his advice in statistical analyses.

I would like to thank Jonathan Rife, Steve Schartz, and Tom Kolins for their assistance in soil physical analyses. I thank Karen Nuzum, Katherina Kotoyantz, Suzanne Larson, and Rob Unruh for their assistance in key punch, graphing, and calculating the data.

Many thanks are due my mother and father for their patience and encouragement through the entire period of study. Sincere appreciation is also due the Royal Thai Government for a supporting scholarship.

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INTRODUCTION

Increased agriculture production is necessary to support a rapidly growing population in most areas of the world. A major practice which has increased crop production is the use of fertilizers. Nitrogen fertilizer is a major fertilizer applied to soils because nitrogen is a vitally important plant nutrient. Furthermore, intensive agriculture is widely practiced at the present time and fertilizer application, therefore, is needed to maintain this production. In the United States, the total nitrogen fertilizers applied in 1959 and 1978 were 2,738,047 and 9,973,491 metric tons, respectively (USDA,1979). The total amount of nitrogen fertilizer used in Kansas was 74,168 (USDA,1960) and 602,282 metric tons (Page,1979) for 1959 and 1979, respectively.

Soil physical properties refer to mechanical behavior of solid, liquid, and gas phases in the soil system. They are involved either directly or indirectly in plant growth. It is well known that fertile soils are not always productive soils if the physical conditions of these soils are not appropriate for plant growth. Some soils contain adequate amounts of essential plant nutrients but compaction limits seedling emergence (crust) and/or root penetration (pans). Plants on these soils cannot grow properly and cannot produce large yields. Poor soil physical conditions limit plant ability to absorb soil nutrients.

The continuous high applications of fertilizers, especially single nutrient fertilizers, can eventually cause accumulation of some cations and an imbalance of nutrients in soils. This can create serious problems for plant growth because of toxicity and/or deficiency, osmotic pressure, and soil moisture stress.

The marked increase in nitrogen fertilizer use in recent years has generated growing interest in the influence of various nitrogen sources on the physical and chemical properties of soils, especially when long-term application are involved.

The objective of the study reported in this thesis was to evaluate the influence of long-term applications of various nitrogen sources on soil physical and chemical properties. Four forms of nitrogen fertilizer (anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate solution) were applied at three field locations (Manhattan, Ottawa, and two field sites at Powhattan) during the period 1969 through 1978. The application has been 224 kg N/ha applied in the spring of each year except at Powhattan where the rate has been 168 kg N/ha from 1973 through 1978. Corn (Zea mays L.) at Manhattan and Powhattan, and grain sorghum (Sorghum bicolor L. Moench) at Ottawa and Powhattan were grown on the field plots during the ten-year study. After the 1978 harvest, undisturbed soil cores and disturbed soil samples were collected for determination of physical and chemical characteristics in the laboratory.

LITERATURE REVIEW

Physical Properties of Soils

Size distribution of soil aggregates is important because it determines soils susceptibility to movement by wind and water, and because size is important in determining the dimensions of the pore space in cultivated soils. The size of pores, in turn, affects the movement and distribution of water and air in soil, which affect plant growth. Therefore, factors which affect the size distribution of soil aggregates may affect plant growth.

Gifford and Strickling (1958) conducted a field and laboratory experiment evaluating the influence of anhydrous ammonia on water stability of soil aggregates. They observed a trend toward an increase in soil aggregate stability as a result of NH_3 treatment. They also observed that the increased stability was correlated with the total organic matter content ($r = 0.661$) in 1954 and was not as large from 1955 to 1957 as in 1954 because of the bonds between particles being destroyed by microbial activity. The work of Anderson (1955) showed that subsequent to nitrification, the water stability of aggregates of NH_3 -treated soils were equal to or better than that of untreated soils. Andrew (1956) commented that from a practical viewpoint, there was little possibility that anhydrous ammonia as applied in the field would affect structural stability unfavorably because too small a percentage of soil is affected for too short a time.

Leo et al. (1959) studied the effect of long continued use of ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$ and sodium nitrate (NaNO_3) on soils and crops. They stated that there was no consistent large difference in soil aggre-

gation among soils from the various plots when $(\text{NH}_4)_2\text{SO}_4$ and NaNO_3 were applied.

Mazurak and Ramig (1963) studied the effect of perennial grasses and ammonium nitrate (NH_4NO_3) on a Chernozem soil for 20 years. They stated that neither the grasses nor the fertilizer application influenced the stability of the dry or wet aggregates. This result was supported by Peschke (1969) who indicated that nitrogen fertilization did not influence aggregate size and aggregate stability but increased density of aggregates. However, if calcium-ammonium nitrate was applied at 25-125 kg N/ha, Schmid (1959) showed the progressive improvement of the aggregate stability of loess soils by increasing the shading and root mass under a more abundant vegetative cover.

Aldrich et al. (1945) compared the influence of nitrogen fertilizers on soil physical properties. They reported that soils which received NaNO_3 and $(\text{NH}_4)_2\text{SO}_4$ had decidedly fewer aggregates greater than 0.1 mm in size as compared to soils which received $\text{Ca}(\text{NO}_3)_2$ or urea as determined by wet sieving.

Schaller and Stockinger (1953) compared five methods for expressing aggregate data. The results indicated that a single size fraction such as the >2 mm or >1 mm would be as reliable (to within the 1% level of significance) as mean weight diameter (MWD) or the geometric mean diameter (GMD). However, the final selection of an index must be based on the ability of the index to correlate with crop response.

Many investigators have studied the influence of nitrogen fertilizer, especially ammonium fertilizers, on permeability of soils. Aldrich et al. (1945) stated that the rate of water permeability through soils which received NaNO_3 and $(\text{NH}_4)_2\text{SO}_4$ was markedly less than through soils which

received $\text{Ca}(\text{NO}_3)_2$ because, in part at least, a reduction in macropore was brought about by a certain amount of structural breakdown. Urea appeared to decrease permeability of soils somewhat over that of $\text{Ca}(\text{NO}_3)_2$. Jenny et al. (1945) also reported that treating soil with NH_3 or NH_4OH reduced the water percolation rate on most soils. These results agreed with the work of Martin and Richards (1959) who investigated the effect of exchangeable NH_4^+ on soil physical properties at different H^+ levels. They concluded that an increase in exchangeable NH_4^+ with increased H^+ reduced water movement through the soils. Hydraulic conductivity of Hanford sandy loam was markedly reduced by 19% NH_4^+ in the base-saturated soil and 10% NH_4^+ in the acid soils because high NH_4^+ soils were relatively susceptible to puddling. Increase in exchangeable H^+ tended to increase the dispersing action of NH_4^+ . Therefore, in acid soils hydraulic conductivity was decreased more than in base-saturated soils. They also indicated that the observed reduction in water permeability can be explained on the basis of accumulation of exchangeable NH_4^+ in the soils.

Fox et al. (1952) applied NH_4NO_3 in autumn to an eroded acid silty clay soil and found that the NH_4^+ persisted in the surface soil and caused a structural breakdown and crusting on the surface, also decreasing permeability. The degree of dispersion was in proportion to the rate of ammonium applied.

In studies using sodium nitrate (NaNO_3), NaNO_3 greatly reduced and sometimes almost abolished the rate of water intake by soil because of an increased dispersion of the finer fractions of the soil due to an increase in exchangeable sodium (Fireman et al., 1945; Magistad et al., 1944; Anthony and Clark, 1946). Calcium nitrate [$\text{Ca}(\text{NO}_3)_2$] was used in an investigation of soil structure and water movement by Hubbell and

Stubblefield (1948). They found that $\text{Ca}(\text{NO}_3)_2$ increased the percolation rate but did not influence the formation of water-stable aggregates.

The use of $(\text{NH}_4)_2\text{SO}_4$ reduced infiltration rate in a sandy loam soil by an average of 17% each year according to Yamada et al. (1963). They concluded that in the three-year following the first rotation cycle, the average reduction in infiltration rates on plots receiving $(\text{NH}_4)_2\text{SO}_4$ were 7-10% in lucerne rotation, 21% in continuous cotton, and 27% in maize-cotton rotation.

Thijel (1976) reported that saturated hydraulic conductivity of both soil cores and disturbed soil samples from the 1 to 10 cm layer were slightly higher for nitrogen fertilized plots than for unfertilized plots. The nitrogen fertilizer applications to plots slightly increased water content at saturation and at 60 cm water suction. Facek (1972) reported that NPK application rates at 4 times as high as normal for 5 years decreased the plastic limit and water retention capacity by increasing macropores, causing large moisture loss.

Digar (1958) reviewed the results of an experiment to study the effect of continuous application of $(\text{NH}_4)_2\text{SO}_4$, with and without farmyard manure (FYM) in an alluvium clay soil for a period of 10 years. He stated that the moisture content of $(\text{NH}_4)_2\text{SO}_4$ plots was less, probably because in these plots the crop grew more vigorously and also matured later and thereby removed more moisture.

Vincente-Chandler and Silva (1960) applied $(\text{NH}_4)_2\text{SO}_4$ at 900 kg N/ha yearly on Napier, Guinea, Para, and Pangola grasses in tropical pastures. They concluded that N application resulted in the following differences in the upper 7.6 cm of soil: 1) a significant increase in the volume of quickly drained pores with Para, Pangola, and Napier grasses, 2) a

significant increase in the volume of soil pores drained at 60-cm tension with Pangola and Napier grasses, 3) a marked increased in percolation rate with Pangola and Napier grasses, 4) a significantly lower bulk density under Para and Napier grasses, and 5) reduced compaction of the surface soil under all grasses except Guinea. They also reported effects on the 7.6-15.2 cm layer of the Catalina clay. The volume of quickly drained pores, the volume of pores drained at 60-cm tension, and the percolation rate were increased with all four grasses by about 30, 20, and 80%, respectively.

A penetrometer is used to measure the force of penetration of a metal point into the soil. There are many kinds of penetrometers that can be used such as a pocket penetrometer, proctor penetrometer, cone penetrometer and standard split-spoon penetrometer depending on the kind of work. Richards (1941) described an inexpensive penetrometer and showed that the presence of plant roots, soil moisture, and compacted layers in soil affected the penetrometer reading. Shaw et al. (1942) presented the results of four years' experience with a soil penetrometer. They reported that there was a very rapid increase in resistance with decreasing moisture. They also summarized that soil moisture seemed to be the dominant factor that influenced the penetrometer readings. Under field conditions there was no simple relationship between penetrometer readings and soil moisture. In a small area of apparently uniform soil and apparently uniform crop, porosity and root differences are of sufficient magnitude to have large effects on the measurement.

Leo et al. (1959) presented soil penetrometer results from their study. The depths of penetration obtained by the impact penetrometer from $(\text{NH}_4)_2\text{SO}_4$ lime plots, $(\text{NH}_4)_2\text{SO}_4$ with more lime plots, NaNO_3 without lime

plots, and NaNO_3 with lime were 7.14, 7.52, 7.44, and 7.49 cm for topsoils, respectively. They concluded that there was no consistent large difference in penetration from the two different nitrogen sources. Digar (1958) compared the effect of $(\text{NH}_4)_2\text{SO}_4$, with and without farmyard manure (FYM) on penetration. He stated that penetrations were less in the $(\text{NH}_4)_2\text{SO}_4$ without FYM plots than in the plots with FYM.

Thijel (1976) applied nitrogen solution ($\frac{1}{2}$ urea + $\frac{1}{2}$ NH_4NO_3) at corn planting and anhydrous ammonia before tasseling at 0 to 270 kg N/ha for six years. He reported that soil bulk density on nitrogen fertilized plots increased slightly more than on unfertilized plots.

Chemical Properties of Soils

The influence of chemical fertilizers on soil pH has been widely investigated by many soil researchers. Otchere-Boateng and Ballard (1978) applied urea fertilizer to forest soils. Soil pH initially increased as the result of urea hydrolysis to $(\text{NH}_4)_2\text{CO}_3$ and then to NH_4OH , and eventually decreased due to nitrification. Viets et al. (1957) and Leo et al. (1959) reported that the use of NaNO_3 as nitrogen fertilizer increased soil pH slightly.

Many investigators (Adam et al., 1967; Dunton et al., 1954; Leo et al., 1959; Owensby et al., 1969; Rafana and Vicario, 1973; Sims and Atkinson, 1974; Van Cleve and Moore, 1978; Verma and Sarkar, 1973; and Viets et al., 1957) agreed that the application of ammonium fertilizers, particularly $(\text{NH}_4)_2\text{SO}_4$, decreased the soil pH due to nitrification.

Salomon and Smith (1947) concluded that accumulation of organic matter was slightly greater in the $(\text{NH}_4)_2\text{SO}_4$ without lime plot, but differences were too small to affect measurement of CEC. In the work of Leo et al. (1959), soil organic matter content of plots receiving $(\text{NH}_4)_2\text{SO}_4$

and NaNO_3 stayed practically constant throughout the years. Ammonium sulfate may have caused a downward movement of organic matter because the subsoil layers had slightly more organic matter with wider C/N ratio and higher exchange capacity than NaNO_3 plots. Owensby et al. (1969) and Van Cleve and Moore (1978) agreed that fertilization with NH_4NO_3 showed no effect on soil organic matter content in any soil layer tested.

Salomon and Smith (1947) pointed out that $(\text{NH}_4)_2\text{SO}_4$ had little effect on exchangeable NH_4^+ because of nitrification and absorption of NH_4^+ -N by crops. Fiskell et al. (1978) compared several sources of nitrogen (urea, NH_4NO_3 , $(\text{NH}_4)_2\text{SO}_4$, and sulfur-coated urea). They concluded there was no effect of N sources on NH_4^+ -N, Ca, and Mg values. In the 8-month urea study by Otchere-Boateng and Ballard (1978), NO_3^- -N concentration below root zone increased steadily from immediately after fertilization to the end of the study probably due to deep percolation of NO_3^- -N from urea. Niedenthal (1974) investigated the effect of continuous applications of nitrogen as NH_4NO_3 on the chemical properties of a Richfield silt loam soil. Added nitrogen did not influence NH_4^+ -N concentration. The accumulation of NO_3^- -N was significantly increased by nitrogen treatment. The pattern of accumulation indicated NO_3^- moved downward uniformly, as there were no large peaks of NO_3^- accumulation in the soil profile.

Niedenthal (1974) and Sims and Atkinson (1974) reported that available phosphorus decreased as nitrogen rates increased. This was probably because nitrogen stimulated plant growth. Therefore, plants took up more phosphorus to balance the nutrients in the plants. Owensby et al. (1969) stated that available phosphorus increased at 224 kg N/ha in the 0- to 15-cm soil layer because of increased soil acidity. Rennie and Soper

(1958) found that increased utilization of phosphorus occurred only when the applied nitrogen was in the ammonium form. Nitrate sources of nitrogen were relatively ineffective.

The increased acidity of soils due to continuous applications of nitrogen fertilizers has several effects on soil chemical properties. Abruna et al. (1958) found that high rates of application of NH_4NO_3 and $(\text{NH}_4)_2\text{NO}_3$ caused severe reduction in exchangeable base levels within a year after beginning N applications. In addition, exchangeable K was lost from soils faster than other bases. The accumulation of bases in the subsoil zone leached out of upper horizons was observed.

Fox et al. (1952), Sims and Atkinson (1974), Salomon and Smith (1947), and Volk and Tidmore (1946) observed that application of ammonium fertilizers influenced exchangeable K very little. But Owensby et al. (1969) found that exchangeable K decreased as nitrogen rate increased from 0- to 67- kg N/ha, and then K rose to its maximum at 224 kg N/ha. Increased use of K due to greater vegetative growth lowered K supplies at lower N levels, but pH effects on K availability were great enough to overcome plant use at higher N levels.

Fox et al. (1952) investigating NH_4^+ ion effect on soil chemical properties found that little change in the exchangeable Ca^{++} and Na^+ status of the soil occurred at the low to moderate rates of NH_4^+ application. In the plots receiving 90 kg N/ha, however, a marked reduction of exchangeable Ca^{++} from 14.5 me/100 g to 11.6 me/100 g, and of exchangeable Na^+ from 0.12 me/100 g to 0.04 me/100 g were obtained. Exchangeable Mg^{++} was slightly affected.

High rates application of acidifying nitrogen fertilizers caused downward movement of calcium and magnesium in a study by Adams et al.

(1967). In another study, Otchere-Boateng and Ballard (1978), investigating urea fertilizer in some forest soils, concluded that leaching of Ca, Mg, K, and Na declined with the increase in pH caused by urea hydrolysis soon after urea application. Leaching of Ca, Mg, K, and Na increased with the declining pH caused by nitrification, the divalent cations being more affected. This effect is presumably accounted for by pH-dependent cation exchange capacity.

Sims and Atkinson (1974) and Allured and Thompson (1973) observed that exchangeable Ca was decreased in the upper 15 cm of soil when ammonium fertilizer was added to soil. This was probably due to the leaching of Ca^{++} with NO_3^- to the deeper depths. Volk and Tidmore (1946) summarized that nitrogen fertilizers lowered exchangeable Ca except where fertilizers were added that contained Ca.

Nitrogen fertilizers can indirectly affect micronutrient availability because of changes in soil pH. In a study reported by Sims and Atkinson (1974), the addition of nitrogen fertilizer to Moury soil significantly increased exchangeable Mn and the concentration of molybdenum. Differences in Mn concentration and molybdenum concentration were greatest at 77 days and 40 days after transplanting, respectively. Field studies with corn in Michigan by Wolcott et al. (1964) showed that acidifying nitrogen carriers increased the uptake of manganese, zinc, and boron, while tending to depress uptake of molybdenum and copper.

Niedenthal (1974), studying the effects of continued application of nitrogen on the chemical composition of irrigated soil, reported that nitrogen treatment increased CEC, extractable Fe, and extractable Mn, while having no effect on soil DTPA-extractable Cu and Zn.

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METHODS AND MATERIALS

The field study consisted of a block design with five treatments and four locations as blocks. Treatments consisted of four nitrogen sources and a check. Treatments were not randomized in each block. The experiment was located at; a) Manhattan, Riley County, b) Ottawa, Franklin County, and c) Powhattan, Brown County. The soils of these three experimental areas are the following: a) Manhattan; Smolan silty clay loam (fine, montmorillonitic, mesic, Pachic Argiustoll), b) Ottawa; Woodson silt loam (fine, mixed, thermic, Abruptic Agriaquoll), c) Powhattan; Grundy silty clay loam (fine, montmorillonitic, mesic, Aquic Argiudoll).

In each block, the sources of nitrogen fertilizer were anhydrous ammonia (NH_3), ammonium nitrate (NH_4NO_3), urea, and a 28% N (32% N at Ottawa) urea-ammonium nitrate solution (UAN). Each nitrogen fertilizer was applied at the rate of 224 kg N/ha from 1969 through 1978 except at Powhattan where the rate was 168 kg N/ha from 1973 through 1978. Corn (Zea mays L.) at Manhattan and Powhattan and grain sorghum (Sorghum bicolor L. Moench) at Ottawa and Powhattan were grown on the field plots during the ten-year study. The field plot diagram for each location is shown in Fig. 1. A check plot (no applied N) was in each block. Individual plots were 6.1 by 15.2 m at Ottawa and 4.6 by 15.2 m at both Powhattan and Manhattan.

Soil Sampling

Disturbed and undisturbed soil samples were collected at Powhattan (grain sorghum), Manhattan, and Powhattan (corn) on 21, 27, and 28 October

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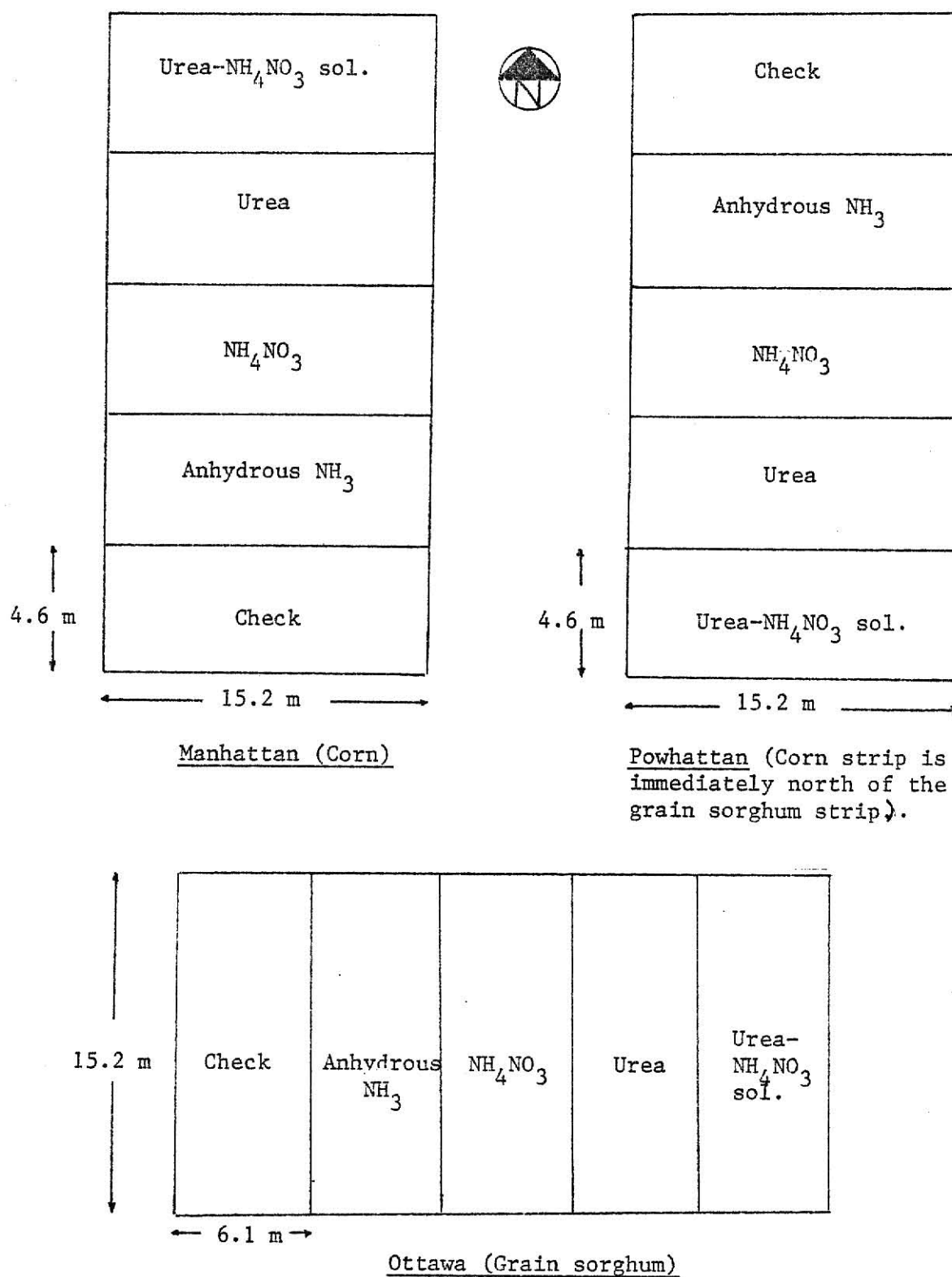


Fig. 1. The diagram of experiment plot design at the three locations; Manhattan, Powhattan, and Ottawa.

1978, respectively. Ottawa was sampled on 11 November 1978.

Soil samples were taken from the two center crop rows of each plot. Four sets of samples were taken from each individual plot, two per center crop row. A double-cylinder, hammer-driven core sampler was used to obtain the undisturbed soil core samples. Soil cores were 7.6 cm in diameter and 7.6 cm tall and taken centered at soil depths of 10 cm and 25 cm. After soil cores were taken, they were sealed in plastic and wax and stored at 5°C until analyzed. The undisturbed soil core samples were used for determining saturated hydraulic conductivity; soil water content at saturation, -0.33 bar, and -15 bars soil water potential; penetrometer resistance; and dry bulk density.

Four sets of disturbed soil samples from each plot were collected from the 6 to 14 cm and the 21 to 29 cm layers, placed in burlap bags, and air dried. They were used in determination of size distribution of water-stable aggregates, soil compactibility, particle-size distribution, and chemical properties. Before determining soil compactibility and particle-size distribution, the four soil samples from each plot were combined into one composite sample by taking 1500 g of soil from each sample and mixing them thoroughly.

Soil Physical Properties Analyses

The analysis for size distribution of water-stable aggregates was conducted using the wet-sieving technique described by Kemper and Chepil (1965). Moistened soil samples were passed through an 8-mm sieve and only material between 4.76 mm and 8 mm were used in the analysis. Twenty-five gram soil samples (4.76 to 8 mm material) were soaked for 10 minutes on the upper screen (2.0 mm) of sieve sets. The samples were then wet-sieved in Yoder-type machine at a rate of 38 strokes per minute (distance

of 3.8 cm) for 10 minutes. Five sets of sieves with sieve openings of 2.0, 1.0, 0.5, and 0.1 mm were used to retain the aggregates. The aggregate masses from three, 25-g samples (75 g total) were combined after wet sieving for each analysis. Sand and gravel were determined by dispersing the aggregates in sodium hexametaphosphate solution and washing through the set of sieves. The weight of aggregates on each sieve size was determined by subtracting the weight of sand and gravel from the weight of the oven-dry material retained after the wet-sieving. The results were reported as MWD (mean weight diameter) and GMD (geometric mean diameter).

✓ The compaction studies for determining the optimum water content (g/g) for compaction and the maximum bulk density (g/cm^3) under a given compactive effort were made according to the low compaction procedure for soil materials passing through a 4.76 mm sieve described by Felt (1965). Bulk density at different soil water contents was determined by using a mold (10.2 cm in diameter and 11.6 cm tall) and a 2.49 kg rammer. The soil samples were compacted in three equal layers and each layer received 25 blows of the rammer dropped from a height of 30.5 cm above the soil surface. The optimum water content for compaction and maximum bulk density were found by using a fifth power regression equation generated using computer regression analysis of the compactibility data.

/ Particle size analysis using the hydrometer method was conducted as described by Day (1965). Soil was passed through a 2 mm sieve and 40 g sample taken for analysis. One hundred ml of sodium hexametaphosphate solution (50 g of sodium hexametaphosphate/liter of distilled water) was used as the dispersion agent. The hydrometer readings were taken at 1/2, 1, 3, 10, 20, 30, 45, 60, 90, 120, 240, 600, and 720 minutes after mixing

of the suspension. The analyses were made in a constant temperature (20°C). The results were reported as the whole number percentage of sand (0.05-2 mm), coarse silt (0.02-0.05 mm), fine silt (0.002-0.02 mm) and clay (<0.002 mm).

X Saturated hydraulic conductivity was determined by using the constant-head method described by Klute (1965). Soil cores were allowed to saturate with tap water for at least 16 hours. A water depth of 5.0 cm was maintained on the soil cores during the test period. Water was allowed to drain freely from the bottom surface of the soil core. The volume of water outflow per unit time was measured until a definite equilibrium was established. With that, the test was considered complete. The saturated hydraulic conductivity values are reported in cm/hr.

X Water content of soils at saturation and -0.33 bar soil water potential were determined after the saturated hydraulic conductivity test. The soil cores were weighed immediately after the saturated hydraulic conductivity test was completed for determination of the saturation water content. Water content at -0.33 bar soil water potential was determined using a ceramic plate system. Soil water content by volume (cm^3/cm^3) was calculated at both saturation and -0.33 bar soil water potential.

Penetrometer resistance measurements were made in the upper surface of the undisturbed soil samples as described by Davidson (1965). The penetrometer was equipped with a proving ring of 0 to 22.7 kg capacity, a LC-2B dial indicator (manufactured by Soil Test Inc., 2205 Lee Street, Evanston, IL 60202), and a 60° cone tip with a base diameter of 6.35 mm. The penetrometer readings were taken immediately after removing the undisturbed soil cores from the ceramic plate after equilibrium at -0.33

bar soil water potential. The cone tip was forced downward into the soil at a rate of 4 cm/minute to a depth of 4.0 cm. Three penetrometer readings from each undisturbed core were averaged and then converted to penetrometer force (kg) by using a calibration equation. The penetrometer resistance was calculated by dividing the penetrometer force (kg) by the area of the cone base (cm^2), and reported as kg/cm^2 .

The dry bulk density determinations were made after penetrometer resistance measurements by using the core method procedure described by Blake (1965). The undisturbed soil cores were placed in an oven at 105°C for at least 48 hours, and then weighed. The bulk density was calculated by dividing the oven-dry mass (g) by the soil volume (cm^3), and reported in g/cm^3 .

Soil water content at -15 bars soil water potential was determined after the undisturbed soil cores were removed from the oven and crushed to pass a 2-mm sieve. Water content was then determined at -15 bars soil water potential using a cellulose acetate membrane pressure system. The water content by weight (g/g) was determined and was converted to the volume basis (cm^3/cm^3) using the bulk density of each individual soil core. Soil water content by volume (cm^3/cm^3) is reported.

Soil Chemical Properties Analyses

The representative soil samples ground to pass through a 2-mm screen were used for soil chemical properties determination. Soil chemical properties were determined by the Soil Testing Laboratory at Kansas State University. Soil pH was measured and read in distilled water by using a pH-meter equipped with glass and reference electrodes as described by McLean (1975). Ammonium-nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N) were assayed colorimetrically by using a spectrophotometer

at wavelengths of 660 nm and 520 nm, respectively, as described by Carson (1975). Organic matter content was determined by a modified Walkley-Black procedure as outlined by Graham (1948). Phosphorus was tested by using the Bray-1 method described by Knudson (1975). Potassium, calcium, magnesium, and sodium were extracted by ammonium acetate solution and measured by atomic absorption for calcium and magnesium and flame photometer for potassium and sodium as given by Carson (1975). Cation exchange capacity was determined by saturating the soil sample with barium solution and then replacing barium by ammonium ions. The replaced barium ions were measured by atomic absorption as outlined by Jackson (1958). Copper, iron, manganese, and zinc were extracted by using DTPA extraction and measured by atomic absorption spectrophotometry as presented by Lindsay and Norwell (1978).

Statistical Analyses

The values for soil physical and chemical properties from four soil samples in each plot were averaged before making statistical analyses. The statistical analyses were made regarding the experimental design as a randomized complete block (four blocks and five treatments). Analysis of variance was used in determining if there were significant differences between treatments and blocks at the 5% level for each soil physical and chemical property at each soil depth. Duncan's Multiple Range Test was used for comparing the treatment and block means. The Statistical Analyses System (SAS) computer package was used in analyzing data as guided by Helwig (1978).

RESULT AND DISCUSSION

Soil Physical Properties

The size distribution of water-stable aggregates obtained using 2, 1, 0.5, and 0.1 mm size sieves is reported in Table 1. Table 1 data show that in the 6 to 14 cm layer, the anhydrous NH_3 treatment has the highest GMD and MWD values, while the check treatment has the lowest values. In the 21 to 29 cm layer, the highest GMD and MWD values were found in the check treatment. However, an analysis of variance of soil aggregate stability at each depth showed no significant difference at the 5% level between treatments for either the GMD or the MWD. The Duncan's Multiple Range Test showed no significant differences among the four treatments receiving nitrogen. In Table 2, soil aggregate stability at each depth was significantly different between blocks for both the GMD and the MWD. Noticeably, the two sites at Powhattan (growing corn and grain sorghum) were not different according to Duncan's Multiple Range Test except for the GMD in the 21 to 29 cm layer.

Compaction refers to the increase in density of soil as a result of applied loads or pressure. There is an identifiable relationship among soil bulk density, compactive effort, and soil water content. The soil density under a constant compactive effort increases progressively with increasing water content to a maximum and then decreases with further additions of water. This maximum bulk density occurs at the optimum water content for compaction. The optimum water content for compaction and maximum bulk density are influenced by organic matter and clay content. Increasing the organic matter content causes a decrease in the maximum

Table 1. Size distribution of water-stable aggregates shown as GMD (mm) and MWD (mm) in two soil layers of the five treatments.

Treatment	GMD	MWD
	mm	mm
<u>Soil layer at 6-14 cm</u>		
Check	0.209 a*	0.610 b*
Anh.NH ₃	0.280 a	0.845 a
NH ₄ NO ₃	0.240 a	0.704 ab
Urea	0.254 a	0.795 a
Urea-NH ₄ NO ₃	0.240 a	0.747 ab
	<u>Significance level</u>	
	0.273	0.057
<u>Soil layer at 21-29 cm</u>		
Check	0.608 a*	1.207 a*
Anh.NH ₃	0.530 a	1.077 ab
NH ₄ NO ₃	0.477 a	0.964 b
Urea	0.454 a	0.969 b
Urea-NH ₄ NO ₃	0.455 a	0.946 b
	<u>Significance level</u>	
	0.246	0.102

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 2. Size distribution of water-stable aggregates shown as GMD (mm) and MWD (mm) in two soil layer of the four blocks.

Block	GMD	MWD
	mm	mm
<u>Soil layer at 6-14 cm</u>		
Ott. (Grain sorghum)	0.195 b*	0.508 c*
Powh. (Corn)	0.315 a	0.962 a
Manh. (Corn)	0.204 b	0.669 b
Powh. (Grain sorghum)	0.266 a	0.823 a
	<u>Significance level</u>	
	0.002	0.001
<u>Soil layer at 21-29 cm</u>		
Ott. (Grain sorghum)	0.305 c*	0.720 b*
Powh. (Corn)	0.807 a	1.414 a
Manh. (Corn)	0.296 c	0.754 b
Powh. (Grain sorghum)	0.612 b	1.243 a
	<u>Significance level</u>	
	0.001	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

bulk density and an increase in the optimum water content for compaction. Therefore, factors which influence organic matter content influence soil compactibility.

The soil compactibility curves from the four blocks and five treatments at two depths are shown in Figs. 2 and 3. Fifth order regression equations were generated from the data and used in calculating the maximum bulk density and the optimum water content for compaction. The results are listed in Table 3. Analysis of variance of the soil compactibility data showed no difference for either the optimum water content for compaction or the maximum bulk density. Also, there was no difference between treatment means according to Duncan's Multiple Range Test. In Table 4, the block means for both layers are presented. The Ottawa and Manhattan blocks were not significantly different in either layer for either compactibility property. The two Powhattan blocks were significantly different only in the 21 to 29 cm layer for maximum bulk density.

The clay, fine silt, coarse silt, and sand percentages for the five treatments and two layers are given in Table 5. An analysis of variance and the Duncan's Multiple Range Test indicated no significant difference between treatments in the four particle-size ranges for either layer. The four particle-size ranges were significantly different between blocks for both layers as presented in Table 6.

Values of hydraulic conductivity (K) vary widely ranging from <0.0025 cm/hr to >25 cm/hr (Smith and Browning, 1946). Soils with a hydraulic conductivity of less than 0.0025 cm/hr are poorly drained, while those with hydraulic conductivity greater than 25 cm/hr do not hold enough water for good plant growth. Conductivity decreases with decreasing pore space and is sensitive to changes in cation content, which affects the degree of hydration or swelling of clay colloids. Entrapment of air greatly

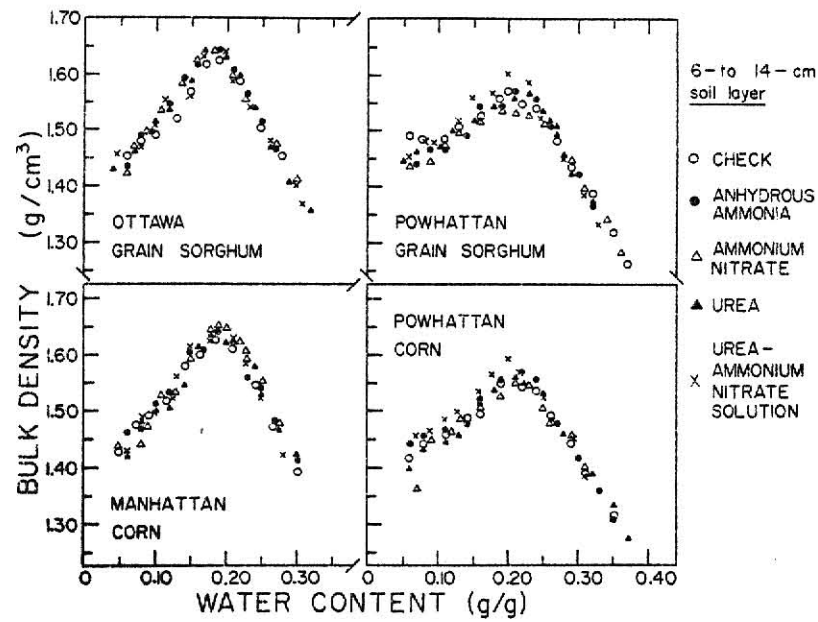


Fig. 2. Soil compactibility cures from five treatments and four blocks at the 6 to 14 cm layer.

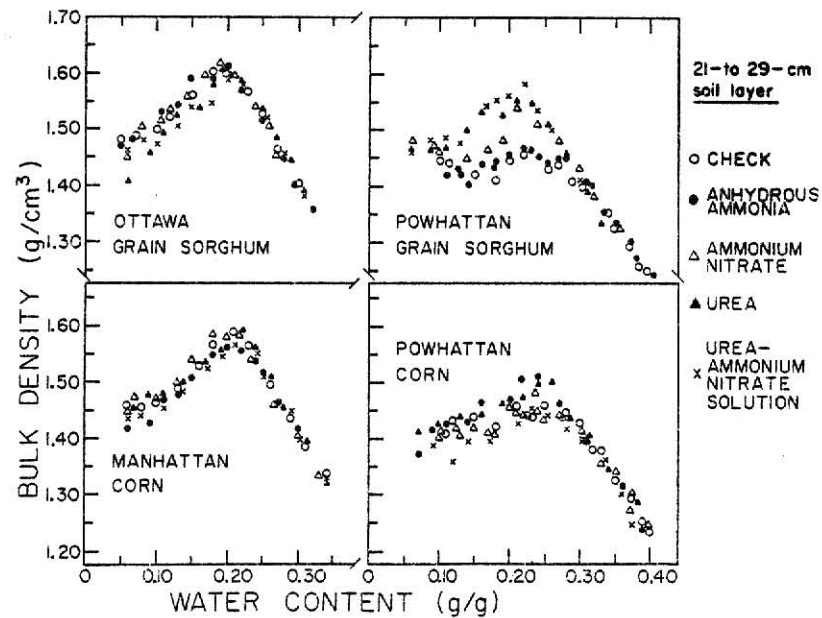


Fig. 3. Soil compactibility curves from five treatments and four blocks at the 21 to 29 cm layer.

Table 3. Mean values of optimum water content for compaction (g/g) and maximum soil bulk density (g/cm³) of the five treatments at two soil layers.

Treatment	Opt.w	Max. bulk density
<u>Soil layer at 6-14 cm</u>	g/g	g/cm ³
Check	0.201 a*	1.584 a*
Anh.NH ₃	0.198 a	1.593 a
NH ₄ NO ₃	0.197 a	1.584 a
Urea	0.202 a	1.586 a
Urea-NH ₄ NO ₃	0.197 a	1.601 a
	<u>Significance level</u>	
	0.688	0.280
<u>Soil layer at 21-29 cm</u>		
Check	0.220 a*	1.517 a*
Anh.NH ₃	0.217 a	1.529 a
NH ₄ NO ₃	0.219 a	1.540 a
Urea	0.213 a	1.545 a
Urea-NH ₄ NO ₃	0.216 a	1.536 a
	<u>Significance level</u>	
	0.889	0.796

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 4. Mean values of optimum water content for compaction (g/g) and maximum soil bulk density (g/cm³) of the four blocks at two soil layers.

Block	Opt.w	Max. bulk density
	g/g	g/cm ³
<u>Soil layer at 6-14 cm</u>		
Ott. (Grain sorghum)	0.188 a*	1.624 a*
Powh. (Corn)	0.211 b	1.549 b
Manh. (Corn)	0.191 a	1.628 a
Powh. (Grain sorghum)	0.207 b	1.558 b
	<u>Significance level</u>	
	0.001	0.001
<u>Soil layer at 21-29 cm</u>		
Ott. (Grain sorghum)	0.198 b*	1.595 a*
Powh. (Corn)	0.236 a	1.461 c
Manh. (Corn)	0.209 b	1.570 a
Powh. (Grain sorghum)	0.226 a	1.508 b
	<u>Significance level</u>	
	0.001	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 5. Mean values of particle-size analysis (% of dry wt.) of the five treatments at two soil layers.

Treatment	Clay ($<0.002\text{mm}$)	Fine silt ($0.002-0.02\text{mm}$)	Coarse silt ($0.02-0.05\text{mm}$)	Sand ($0.05-2\text{mm}$)
<hr/> % of dry wt. <hr/>				
<u>Soil layer at 6-14 cm</u>				
Check	33 a*	33 a*	23 a*	11 a*
Anh.NH ₃	33 a	34 a	21 a	12 a
NH ₄ NO ₃	33 a	33 a	22 a	12 a
Urea	33 a	31 a	24 a	13 a
Urea-NH ₄ NO ₃	33 a	32 a	23 a	13 a
	<u>Significance level</u>			
	0.973	0.155	0.834	0.431
<u>Soil layer at 21-29 cm</u>				
Check	39 a*	31 a*	20 a*	10 a*
Anh.NH ₃	37 a	33 a	20 a	11 a
NH ₄ NO ₃	37 a	32 a	20 a	11 a
Urea	36 a	31 a	22 a	11 a
Urea-NH ₄ NO ₃	37 a	32 a	21 a	11 a
	<u>Significance level</u>			
	0.867	0.589	0.605	0.985

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 6. Mean values of particle-size analysis (% of dry wt.) of the four blocks at two soil layers.

Block	Clay ($<0.002\text{mm}$)	Fine silt ($0.002-0.02\text{mm}$)	Coarse silt ($0.02-0.05\text{mm}$)	Sand ($0.05-2\text{mm}$)
<hr/> % of dry wt. <hr/>				
<u>Soil layer at 6-14 cm</u>				
Ott. (Grain sorghum)	27 b*	41 a*	21 b*	11 b*
Powh. (Corn)	36 a	32 b	20 b	12 b
Manh. (Corn)	34 a	23 c	27 a	16 a
Powh. (Grain sorghum)	34 a	33 b	22 b	11 b
	<u>Significance level</u>			
	0.001	0.001	0.012	0.001
<u>Soil layer at 21-29 cm</u>				
Ott. (Grain sorghum)	28 c*	42 a*	19 bc*	11 ab*
Powh. (Corn)	45 a	30 b	16 c	9 b
Manh. (Corn)	36 b	23 c	28 a	13 a
Powh. (Grain sorghum)	39 b	32 b	20 b	10 ab
	<u>Significance level</u>			
	0.001	0.001	0.001	0.087

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

reduces conductivity by blocking soil pores, while a decrease in temperature decreases conductivity by increasing the viscosity of water (Kramer, 1969).

The saturated hydraulic conductivity data and results from this study are presented in Table 7. An analysis of variance and the Duncan's Multiple Range Test of saturated hydraulic conductivity for each layer showed no difference between treatments at the 5% level. The Duncan's Multiple Range Test did indicate significant differences between block means in the 6 to 14 cm layer.

Penetrometer resistance was measured immediately after equilibrium at -0.33 bar of pressure potential. The results are presented in Table 8. An analysis of variance of penetrometer resistance for each layer showed no significant difference between treatments at the 5% level. According to Duncan's Multiple Range Test, treatments in the 6 to 14 cm layer were not different, but in the 21 to 29 cm layer the ammonium nitrate treatment was significantly greater than the other treatments with the exception of anhydrous ammonia. Table 8 also presents the block means for penetrometer resistance. An analysis of variance indicates significant differences between block means.

Water retained by soil is a function of soil texture, organic matter content, and soil porosity. Increasing clay and/or organic matter content will cause an increase in water retained by soil. This is due to the fact that clay and organic matter have a high external surface area which is important at low pressure potentials and also promotes aggregation which increases total porosity which is important at high pressure potentials.

Water content by volume (cm^3/cm^3) determined at three soil water pressure potentials is illustrated in Table 9. These determinations were

Table 7. Mean values of saturated hydraulic conductivity (cm/hr) for the five treatments and for the four blocks at two soil layers.

	Saturated hydraulic conductivity	
	Soil layer (cm)	
	6-14	21-29
	cm/hr	
<u>Treatment</u>		
Check	6.4 a*	1.1 a*
Anh. NH_3	4.2 a	1.0 a
NH_4NO_3	4.6 a	0.7 a
Urea	5.4 a	1.0 a
Urea- NH_4NO_3	3.8 a	1.0 a
	<u>Significance level</u>	
	0.764	0.919
<u>Block</u>		
Ott. (Grain sorghum)	3.7 b*	1.1 a*
Powh. (Corn)	2.6 b	0.5 a
Manh. (Corn)	8.5 a	1.2 a
Powh. (Grain sorghum)	4.7 ab	1.0 a
	<u>Significance level</u>	
	0.054	0.441

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 8. Mean values of penetrometer resistance (kg/cm^2) of five treatments and of four blocks at two soil layers.

	Penetrometer resistance	
	Soil layer (cm)	
	6-14	21-29
	kg/cm^2	
<u>Treatment</u>		
Check	8.9 a*	10.0 b*
Anh. NH_3	10.0 a	11.5 ab
NH_4NO_3	10.2 a	12.4 a
Urea	9.9 a	10.2 b
Urea- NH_4NO_3	7.6 a	10.2 b
	<u>Significance level</u>	
	0.367	0.053
<u>Block</u>		
Ott. (Grain sorghum)	13.6 a*	13.9 a*
Powh. (Corn)	9.6 b	9.5 c
Manh. (Corn)	5.7 c	12.0 b
Powh. (Grain sorghum)	8.3 bc	8.0 c
	<u>Significance level</u>	
	0.001	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

made using the disturbed soil cores. An analysis of variance of water content at saturation, at -0.33 bar, and at -15 bar soil water pressure potentials indicated no significant difference between treatments in either layer. Also, the Duncan's Multiple Range Test showed no difference among the five treatments. The water content block means were significantly different according to an analysis of variance (Table 10).

Soil bulk density of the undisturbed soil cores from the five treatments and four blocks at two depths is presented in Table 11. An analysis of variance and the Duncan's Multiple Range Test of soil bulk density at each depth indicated that there was no significant difference between treatments at the 5% level, but there was a significant difference between blocks.

Soil Chemical Properties

Bray-1 extractable phosphorus content, cation exchange capacity, and organic matter content of the five treatments and two soil layers were not affected by nitrogen fertilization (Table 12). An analysis of variance and the Duncan's Multiple Range Test of these three soil chemical properties indicated no significant difference between treatments in either layer. The block means were significantly different except for the organic matter content in the 21 to 29 cm layer (Table 13).

The influence of nitrogen fertilization on soil pH was significant for both soil layers (Table 12). Nitrogen-fertilized treatments had significantly lower soil pH than the check treatment. This was probably because ammonium ions were nitrified to nitrate and released H^+ to the soil in the process (Grunes, 1959). The Duncan's Multiple Range Test showed no significant difference among the four treatments receiving nitrogen. Soil pH of the four blocks was significantly different (Table

Table 9. Mean values of soil water content (cm^3/cm^3) at saturation, -0.33 bar, and -15 bars of pressure potential for the five treatments at two soil layers.

Treatment	Soil water content		
	Pressure potential (bars)		
	0	-0.33	-15
<hr/>			
	cm^3/cm^3		
<hr/>			
<u>Soil layer at 6-14 cm</u>			
Check	0.436 a*	0.320 a*	0.155 a*
Anh.NH ₃	0.420 a	0.331 a	0.158 a
NH ₄ NO ₃	0.432 a	0.323 a	0.152 a
Urea	0.430 a	0.307 a	0.155 a
Urea-NH ₄ NO ₃	0.426 a	0.335 a	0.149 a
	<u>Significance level</u>		
	0.573	0.228	0.791
<u>Soil layer at 21-29 cm</u>			
Check	0.440 a*	0.383 a*	0.227 a*
Anh.NH ₃	0.431 a	0.367 a	0.231 a
NH ₄ NO ₃	0.435 a	0.367 a	0.236 a
Urea	0.436 a	0.367 a	0.231 a
Urea-NH ₄ NO ₃	0.438 a	0.373 a	0.217 a
	<u>Significance level</u>		
	0.732	0.589	0.879

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 10. Mean values of soil water content (cm^3/cm^3) at saturation, -0.33 bar, and -15 bars of pressure potential for the four blocks at two soil layers.

Block	Soil water content		
	Pressure potential (bars)		
	0	-0.33	-15
<hr/>			
	<hr/>		
	cm^3/cm^3		
<hr/>			
<u>Soil layer at 6-14 cm</u>			
Ott. (Grain sorghum)	0.405 c*	0.322 b*	0.146 b*
Powh. (Corn)	0.403 bc	0.340 ab	0.170 a
Manh. (Corn)	0.448 a	0.281 c	0.130 c
Powh. (Grain sorghum)	0.439 bc	0.348 a	0.170 a
<hr/>			
<u>Significance level</u>			
	0.002	0.001	0.001
<hr/>			
<u>Soil layer at 21-29 cm</u>			
Ott. (Grain sorghum)	0.400 c*	0.341 b*	0.187 b*
Powh. (Corn)	0.450 ab	0.408 a	0.283 a
Manh. (Corn)	0.438 b	0.346 b	0.196 b
Powh. (Grain sorghum)	0.456 a	0.391 a	0.248 a
<hr/>			
<u>Significance level</u>			
	0.001	0.001	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 11. Mean values of soil bulk density (g/cm^3) from the five treatments and from the four blocks at two soil layers.

Treatment.	Soil bulk density	
	Soil layer (cm)	
	6-14	21-29
	----- g/cm^3 -----	
Check	1.307 a*	1.351 a*
Anh. NH_3	1.340 a	1.344 a
NH_4NO_3	1.302 a	1.354 a
Urea	1.305 a	1.349 a
Urea- NH_4NO_3	1.309 a	1.358 a
	<u>Significance level</u>	
	0.705	0.943
<u>Block</u>		
Ott. (Grain sorghum)	1.396 a*	1.420 a*
Powh. (Corn)	1.313 b	1.342 b
Manh. (Corn)	1.225 c	1.332 b
Powh. (Grain sorghum)	1.316 b	1.311 b
	<u>Significance level</u>	
	0.001	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 12. Mean values of available phosphorus (ppm), pH, CEC (meq/100g), and organic matter content (%) of soil for the five treatments at two soil layers.

Treatment	P	pH	CEC	OM
	ppm		meq/100g	%
<u>Soil layer at 6-14 cm</u>				
Check	27 a*	6.4 a*	21.7 a*	2.3 a*
Anh.NH ₃	23 a	5.7 b	21.7 a	2.3 a
NH ₄ NO ₃	22 a	5.7 b	22.0 a	2.4 a
Urea	22 a	5.7 b	21.3 a	2.4 a
Urea-NH ₄ NO ₃	22 a	5.7 b	21.9 a	2.4 a
	<u>Significance level</u>			
	0.297	0.001	0.954	0.499
<u>Soil layer at 21-29 cm</u>				
Check	14 a*	6.4 a*	24.8 a*	2.0 a*
Anh.NH ₃	12 a	5.9 b	25.5 a	2.1 a
NH ₄ NO ₃	14 a	5.8 b	25.2 a	2.2 a
Urea	13 a	5.8 b	24.1 a	2.1 a
Urea-NH ₄ NO ₃	15 a	5.9 b	24.3 a	2.1 a
	<u>Significance level</u>			
	0.785	0.001	0.885	0.862

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 13. Mean values of available phosphorus (ppm), pH, CEC (meq/100g), and organic matter content (%) for the four blocks at two soil layers.

Block	P	pH	CEC	OM
<hr/>				
<u>Soil layer at 6-14 cm</u>	ppm		meq/100g	%
Ott. (Grain sorghum)	22 b*	6.7 a*	21.6 b*	2.3 bc*
Powh. (Corn)	21 bc	5.5 c	23.8 a	2.5 a
Manh. (Corn)	32 a	5.3 a	17.4 c	2.2 c
Powh. (Grain sorghum)	17 c	5.8 b	24.2 a	2.4 ab
	<u>Significance level</u>			
	0.001	0.001	0.001	0.003
<hr/>				
<u>Soil layer at 21-29 cm</u>				
Ott. (Grain sorghum)	17 a*	6.5 a*	21.1 b*	2.1 ab*
Powh. (Corn)	8 b	5.8 c	29.7 a	2.0 b
Manh. (Corn)	21 a	5.5 d	18.2 c	2.2 a
Powh. (Grain sorghum)	9 b	6.0 b	28.2 a	2.1 ab
	<u>Significance level</u>			
	0.001	0.001	0.001	0.131

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

13).

The concentration of extractable calcium and magnesium in both soil layers is presented in Table 14. An analysis of variance of these two nutrients showed no significant difference in the 6 to 14 cm layer or in the 21 to 29 cm layer. Also, calcium and magnesium in all five treatments were not different except calcium in the 21 to 29 cm layer according to Duncan's Multiple Range Test. Calcium in the deeper layer was highest in the anhydrous NH_3 treatment and lowest in the ammonium nitrate treatment. The concentration of these two nutrients in the 6 to 14 cm layer was lower than in the 21 to 29 cm layer. Calcium and magnesium concentrations were significantly difference between blocks (Table 15).

An analysis of variance demonstrated that extractable sodium was not significantly affected by nitrogen fertilization (Table 14). According to Duncan's Multiple Range Test, sodium in the nitrogen-fertilized treatments was decreased relative to the check treatment. Among the treatments receiving nitrogen, sodium concentrations were not different in either layer. Table 15 illustrates that there is a significant difference in sodium content between blocks.

Extractable potassium in either layer was not significantly affected by nitrogen fertilization (Table 14). However, the extractable potassium content in nitrogen-fertilized treatments was slightly lower than that in the check treatment in each layer. The Duncan's Multiple Range Test showed no difference in potassium among the four treatments receiving nitrogen. An analysis of variance indicated a significant difference in potassium concentration between blocks for both soil layers (Table 15).

The concentration of DTPA extractable copper is shown in Table 16.

Table 14. Mean values of exchangeable calcium, magnesium, sodium, and potassium for the five treatments at two soil layers.

Treatment	Ca	Mg	Na	K
<u>Soil layer at 6-14 cm</u>				
	ppm	ppm	ppm	ppm
Check	3540 a*	732 a*	46 a*	179 a*
Anh.NH ₃	3401 a	667 a	30 b	142 b
NH ₄ NO ₃	3355 a	695 a	29 b	156 ab
Urea	3407 a	659 a	30 b	141 b
Urea-NH ₄ NO ₃	3480 a	633 a	33 b	150 ab
	<u>Significance level</u>			
	0.827	0.653	0.056	0.098
<u>Soil layer at 21-29 cm</u>				
Check	4372 ab*	1034 a*	81 a*	148 a*
Anh.NH ₃	4521 a	1001 a	50 ab	140 a
NH ₄ NO ₃	3764 b	876 a	41 b	131 a
Urea	4053 ab	891 a	53 ab	139 a
Urea-NH ₄ NO ₃	4185 ab	910 a	56 ab	130 a
	<u>Significance level</u>			
	0.183	0.291	0.174	0.534

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 15. Mean values of exchangeable calcium, magnesium, sodium, and potassium for the four blocks at two soil layers.

Block	Ca	Mg	Na	K
<u>Soil layer at 6-14 cm</u>				
	ppm	ppm	ppm	ppm
Ott. (Grain sorghum)	3782 a*	411 b*	46 a*	85 c*
Powh. (Corn)	3749 a	906 a	28 bc	84 c
Manh. (Corn)	2516 b	509 b	21 c	293 a
Powh. (Grain sorghum)	3698 a	882 a	38 ab	153 b
	<u>Significance level</u>			
	0.001	0.001	0.002	0.001
<u>Soil layer at 21-29 cm</u>				
Ott. (Grain sorghum)	4123 b*	583 c*	71 a*	87 c*
Powh. (Corn)	4971 a	1345 a	59 a	103 c
Manh. (Corn)	3133 c	674 c	24 b	200 a
Powh. (Grain sorghum)	4489 ab	1167 b	69 b	101 b
	<u>Significance level</u>			
	0.001	0.001	0.018	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

In the 6 to 14 cm layer, the nitrogen fertilized treatments tended to have higher DTPA extractable copper concentration than the concentration in the check treatment. Hodgson (1963) has shown decreasing soil pH causes an increase in copper availability. Extractable copper in the 6 to 14 cm layer was not different at the 5% level among the four nitrogen-fertilized treatments according to Duncan's Multiple Range Test. In the 21 to 29 cm layer, an analysis of variance revealed a significant difference between treatment at the 5% level. Anhydrous NH_3 and NH_4NO_3 which is not significant from urea or urea- NH_4NO_3 solution treatment had the highest copper concentration. The urea and urea- NH_4NO_3 solution treatments had the lowest extractable copper content. Table 17 indicates a significant difference in extractable copper concentration between blocks for both layers.

The concentration of DTPA extractable iron was not affected by nitrogen fertilization according to an analysis of variance and Duncan's Multiple Range Test (Table 16). In Table 17, extractable iron in the 6 to 14 cm layer was significantly different for blocks. The extractable iron concentration in the 21 to 29 cm layer was not significantly different between blocks.

An analysis of variance illustrated that DTPA extractable manganese was significantly increased by nitrogen fertilization in the 6 to 14 cm layer but was not significantly influenced in the 21 to 29 cm layer (Table 16). In each soil layer the nitrogen-fertilized treatments had significantly higher manganese concentration than the check treatment when tested by Duncan's Multiple Range Test. This was due to the acidifying effect of nitrogen fertilizers causing soil pH to decrease and making the manganese more available. The concentration of extractable manganese was

Table 16. Mean values of DTPA extractable copper, iron, manganese, and zinc for the five treatments at two soil layers.

Treatment	Cu	Fe	Mn	Zn
<u>Soil layer at 6-14 cm</u>				
	ppm	ppm	ppm	ppm
Check	1.57 b*	53.4 a*	23.0 b*	0.86 a*
Anh.NH ₃	1.95 a	67.2 a	36.4 a	0.72 b
NH ₄ NO ₃	1.87 a	56.9 a	37.6 a	0.73 b
Urea	1.75 ab	53.9 a	38.5 a	0.72 b
Urea-NH ₄ NO ₃	1.75 ab	64.0 a	37.0 a	0.69 b
	<u>Significance level</u>			
	0.055	0.659	0.002	0.035
<u>Soil layer at 21-29 cm</u>				
Check	1.94 b*	49.0 a*	19.0 b*	0.58 a*
Anh.NH ₃	2.18 a	54.4 a	27.6 a	0.54 a
NH ₄ NO ₃	2.01 ab	53.9 a	27.9 a	0.47 a
Urea	1.83 b	52.4 a	27.2 a	0.50 a
Urea-NH ₄ NO ₃	1.83 b	50.5 a	26.6 ab	0.47 a
	<u>Significance level</u>			
	0.008	0.929	0.130	0.758

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 17. Mean values of DTPA extractable copper, iron, manganese, and zinc for the four blocks at two soil layers.

Block	Cu	Fe	Mn	Zn
<hr/>				
<u>Soil layer at 6-14 cm</u>	ppm	ppm	ppm	ppm
Ott. (Grain sorghum)	1.32 b*	41.3 c*	15.9 c*	1.21 a*
Powh. (Corn)	2.27 a	74.2 a	33.4 b	0.57 c
Manh. (Corn)	1.37 b	51.1 bc	52.0 a	0.48 c
Powh. (Grain sorghum)	2.15 a	69.6 ab	36.7 b	0.71 b
	<u>Significance level</u>			
	0.001	0.020	0.001	0.001
 <u>Soil layer at 21-29 cm</u>				
Ott. (Grain sorghum)	1.49 c*	54.8 ab*	13.0 c*	0.87 a*
Powh. (Corn)	2.61 a	50.2 ab	21.8 b	0.27 c
Manh. (Corn)	1.53 c	43.1 b	42.0 a	0.37 bc
Powh. (Grain sorghum)	2.19 b	59.7 a	25.8 b	0.53 b
	<u>Significance level</u>			
	0.001	0.110	0.001	0.001

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

not different among the four treatments receiving nitrogen in either layer. An analysis of variance showed significant differences in manganese concentration between blocks in both layers (Table 17).

In the surface soil, nitrogen fertilization significantly decreased the DTPA extractable zinc concentration (Table 16) due to decreasing the soil pH (Table 12). This result is opposite the findings of Singh et al. (1968) and Thorne (1957). This is possibly because plants could take up more zinc when soil pH was decreased (Hodgson, 1963). Consequently, less zinc concentration remained in soil. Among the treatments receiving nitrogen there was no difference in zinc concentration.

No difference appeared in zinc concentration in the deeper layer according to an analysis of variance and the Duncan's Multiple Range Test. Zinc content was significantly different between blocks in each soil layer (Table 17).

The soil ammonium-nitrogen ($\text{NH}_4^+\text{-N}$) concentration in the 6 to 14 cm layer and in the 21 to 29 cm layer of the five treatments is presented in Table 18. An analysis of variance indicated no difference in the $\text{NH}_4^+\text{-N}$ concentration between treatments in the 6 to 14 cm layer at the 5% level but there was a significant difference in the 21 to 29 cm layer. Urea and urea-ammonium nitrate solution treatments had significantly greater $\text{NH}_4^+\text{-N}$ concentrations than the check treatment according to Duncan's Multiple Range Test. However, $\text{NH}_4^+\text{-N}$ concentration was not significantly different among the four nitrogen fertilization treatments according to Duncan's Multiple Range Test. Table 19 indicates significant differences in the $\text{NH}_4^+\text{-N}$ concentration between blocks at the 5% level in each soil layer.

The nitrate-nitrogen ($\text{NO}_3^-\text{-N}$) concentration was much greater than

Table 18. Mean values of nitrate-nitrogen (NO_3^- -N) and ammonium-nitrogen (NH_4^+ -N) for the five treatments at two soil layers.

Treatment	NO_3^- -N	NH_4^+ -N
<u>Soil layer at 6-14 cm</u>	ppm	ppm
Check	10.4 b*	4.1 b*
Anh. NH_3	24.0 a	8.5 ab
NH_4NO_3	26.4 a	7.5 ab
Urea	24.8 a	10.8 a
Urea- NH_4NO_3	30.6 a	12.2 a
	<u>Significance level</u>	
	0.009	0.068
<u>Soil layer at 21-29 cm</u>		
Check	9.3 b*	4.0 b*
Anh. NH_3	28.0 a	6.8 ab
NH_4NO_3	26.5 a	6.6 ab
Urea	28.6 a	8.8 a
Urea- NH_4NO_3	30.3 a	7.3 a
	<u>Significance level</u>	
	0.010	0.048

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

Table 19. Mean values of nitrate-nitrogen (NO_3^- -N) and ammonium-nitrogen (NH_4^+ -N) for the four blocks at two soil layers.

Block	NO_3^- -N	NH_4^+ -N
<hr/>		
<u>Soil layer at 6-14 cm</u>	ppm	ppm
Ott. (Grain sorghum)	13.7 b*	9.9 ab*
Powh. (Corn)	20.0 b	4.6 b
Manh. (Corn)	42.8 a	13.0 a
Powh. (Grain sorghum)	16.5 b	6.9 b
	<u>Significance level</u>	
	0.001	0.020
 <u>Soil layer at 21-29 cm</u>		
Ott. (Grain sorghum)	21.7 b*	8.8 a*
Powh. (Corn)	16.7 b	4.3 c
Manh. (Corn)	41.6 a	7.7 ab
Powh. (Grain sorghum)	18.1 b	5.9 bc
	<u>Significance level</u>	
	0.001	0.015

* Means followed by the same letter are not different at the 0.05 significance level according to Duncan's Multiple Range Test.

the NH_4^+ -N concentration (as shown in Table 18) because NH_4^+ ions in the applied fertilizer were rapidly changed to NO_3^- ions by the nitrification process (Tisdale and Nelson, 1975). An analysis of variance clearly shows that NO_3^- -N concentration is significantly different in both layers with the nitrogen-fertilized treatments having significantly greater NO_3^- -N concentration than the check treatment. No difference was found in the treatments receiving nitrogen. The NO_3^- -N concentration in the four blocks was significantly different (at the 5% level) in both soil layers (Table 19). Due to insect damage it was necessary to disk the Manhattan corn in June 1978. The plots were bare the remainder of the 1978 growing season. This is the likely reason for the very high NO_3^- -N concentration values at Manhattan presented in Table 19.

SUMMARY AND CONCLUSION

The influence of long-term applications of various nitrogen fertilizer sources on soil physical and chemical properties was investigated. Four forms of nitrogen fertilizer (anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate solution) were applied at three field locations during the previous ten years. Undisturbed soil cores at 10 and 25 cm soil depths and disturbed soil samples at 6- to 14-cm and 21- to 29- cm soil layers were collected for laboratory analyses of soil physical and chemical properties.

An analysis of variance was used to test whether or not there was any significant difference between treatments and blocks. Duncan's Multiple Range Test evaluated if treatment and block pairs were significantly difference.

In general, nitrogen fertilization did not significantly influence soil physical properties determined. The GMD and the MWD of water-stable aggregates were greater in the nitrogen fertilized treatments than in the check treatment in the upper layer. In the deeper layer, the check treatment produced the highest values of the GMD and the MWD. The optimum water content for compaction and maximum soil bulk density were not significantly influenced by treatment in either layer. Nitrogen fertilizers did not influence the distribution of soil separates. The ammonium nitrate treatment gave the highest value of penetrometer resistance in both soil layers. An analysis of variance and the Duncan's Multiple Range Test showed no significant difference in soil water content at saturation, at -0.33 bar, and at -15 bars soil water potential in

either layer. No significant difference in soil bulk density from the five treatments was found in either layer. The soil physical properties evaluated were not significantly influenced by nitrogen fertilization compared to the use of no nitrogen fertilizer. In addition, the different nitrogen sources did not produce differences in these soil physical properties.

The results of this study indicate that nitrogen fertilizers have measurable influence on some chemical properties of soil. Nitrogen fertilization significantly decreased soil pH because of the acidifying effect of microbial breakdown of ammonium in the nitrification process. A decrease in soil pH influenced the availability of the micronutrients copper and manganese, making them more available in the acid surface soil. The manganese concentration significantly increased but the zinc concentration significantly decreased in the surface soil as the result of nitrogen fertilization. The copper concentration in the surface soil tended to increase because of nitrogen fertilization. Nitrogen fertilization did not influence the iron concentration.

An analysis of variance showed no significant difference in available phosphorus, CEC, organic matter content, calcium, magnesium, sodium, and potassium in either layer. In the surface soil, phosphorus, calcium, magnesium, sodium, and potassium showed a slightly reduced concentration in the nitrogen fertilized treatments as compared to the check treatment. Forms of nitrogen source did not provide any influence on the soil chemical properties.

The NO_3^- -N concentration in the soil was significantly increased due to nitrogen fertilization. Also, the NO_3^- -N concentration was much higher than NH_4^+ -N concentration probably because microorganisms change

NH_4^+ to NO_3^- in the nitrification process quite rapidly leaving little NH_4^+ from the previous year's application. Nitrogen fertilization tended to increase the NH_4^+ -N concentration in each layer.

The results of this study indicate that application of nitrogen fertilizers influence soil chemical properties more than soil physical properties. No significant differences were found in the soil physical or chemical properties as a result of the forms of nitrogen used.

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INFLUENCE OF VARIOUS NITROGEN SOURCES ON SOIL PHYSICAL
AND CHEMICAL PROPERTIES

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AN ABSTRACT OF A MASTER'S THESIS
submitted in partial fulfillment of the
requirement for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
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1981

ABSTRACT

This investigation evaluated the influence of long-term applications of various nitrogen fertilizers on the physical and chemical properties of three soils. Four forms of nitrogen fertilizer (anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate solution) were applied at three field locations in the spring of each year for ten years. Undisturbed soil cores and disturbed soil samples were taken centered at soil depths of 10 cm and 25 cm in late October and early November of 1978 for determining soil physical and chemical properties in the laboratory.

Analysis of variance indicated no significant difference (at the 5% level) between treatments in size distribution of water-stable aggregates; soil compactibility; soil texture; saturated hydraulic conductivity; penetrometer resistance; water content at saturation, at -0.33 bar, and at -15 bar soil water potential; and soil bulk density at either depth.

Nitrogen fertilization significantly lowered soil pH at both depths. In the surface soil, due to nitrogen fertilization, the concentration of manganese increased significantly, but the concentration of zinc decreased significantly. The copper and iron concentrations were not influenced significantly by nitrogen fertilization.

Analysis of variance indicated that nitrogen fertilization did not affect significantly (at the 5% level) available P, CEC, organic matter content, Ca, Mg, Na, and K in either layer sampled.

There was no significant increase in ammonium-nitrogen in the surface soil but there was a significant increase in the deeper layer

due to nitrogen fertilization. The nitrate-nitrogen concentrations were much higher than the ammonium-nitrogen concentrations and were increased significantly by nitrogen fertilization.

Application of nitrogen fertilizers influenced soil chemical properties more than soil physical properties. The form of nitrogen fertilizer had no significant influence on the soil physical or chemical properties as compared with other nitrogen forms in the research study.