FATE OF UREA AND AMMONIUM NITRATE

WITH VARIOUS CROPS AND SOILS

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Submitted to the Faculty of the Graduate College
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in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1971

126 pp.

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ACKNOWLEDGMENTS

The writer acknowledges deep and abiding gratitude to Dr. Lawrence G. Morrill, his major adviser, without whose guidance and help this study would not have been accomplished. The writer also wishes to acknowledge the very fine help and guidance that he received from the members of his thesis committee: Dr. Billy B. Tucker, Dr. Dale E. Weibel, and Dr. Glenn W. Todd.

Grateful acknowledgment is also made by the writer for the financial support from the National Science Development Board of the Philippines while he was studying at Oklahoma State University.

Deep gratitude is also acknowledged by the writer for Mrs. Claudia R. Melchor, and Mr. and Mrs. Jesus Taganas for the excellent and loving care that they gave to the writer's children during his study.

Above all, the writer is forever indebted to Paulita, his wife, who has always been a continuous source of inspiration, love and understanding to the writer.

As a father, the writer gives heartfelt thanks to his children: David, Lourdes, Junever, Lyman and Jorge for being such very good boys and girls during the long absence of their father and mother away from them.

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CHAPTER I

INTRODUCTION

Among the nutrients absorbed by plants from the soil, nitrogen is utilized in the greatest quantity. This element is also most readily lost from the rhizosphere under soil and climatic conditions that favor plant growth. Consequently, nitrogen fertilization has long been a subject of considerable universal study.

As a fertilizer, nitrogen is applied to crops in various forms. Although numerous studies had been done on the comparative effects of the different nitrogen carriers on the nutrition and growth of crops, conflicting results were noted in these investigations. Some forms were reported to be superior to the others in some cases but inferior in other instances. In view of this, a study was made to determine the relative effects of urea and ammonium nitrate on the nutrient uptake and yield of various crops in different soils of Oklahoma. These two fertilizers were selected for two reasons. One is that they have been studied extensively and yet no conclusive evidence has been reported in the literature to establish the superiority of one over the other. Another reason is that urea and ammonium nitrate, with the exception of anhydrous ammonia which is most common in the United States, are the two common forms of nitrogenous fertilizers all over the world. A second objective of the study was to determine the solubilization and movement of these fertilizers in soils.

CHAPTER II

REVIEW OF LITERATURE

Extensive literature on nitrogen studies has accumulated. It is difficult or almost impossible to cover all of them in this review. Only those that have a direct bearing on this study are reviewed.

Avenues of Nitrogen Losses from Soils

Runoff and Leaching

Fertilizer nitrogen in soils is rapidly converted to ammonium and nitrate, the latter form predominating in well-drained soils. It is possible that losses of nitrogen through runoff could be substantial when soil erosion occurs. The writer has not found literature dealing with quantitative measurements of nitrogen lost through runoff. However, some investigations had been made on the effect of the type of fertilizer material on the amount and kind of nitrogen recovered from runoff. Moe *et al*. (1968) noted that ammonium nitrogen lost by runoff was less from urea than from ammonium nitrate. They attributed the cause of this to the differential ionization of these two fertilizers. On account of the rapid ionization of ammonium nitrate, the ammonium formed was readily adsorbed by the surface soil whereas the relatively slowly ionized urea moved deeper into the soil before substantial ammonium formation occurred. Thus the eroded soil carried away the ammonium (from the ammonium nitrate) that was adsorbed by the surface soil while much of the urea remained.

Concomitant to the loss of nitrogen by runoff is its loss with soil erosion. The factors that influence runoff also affect soil erosion losses in a similar manner. Quantitative measurements of nitrogen losses through soil erosion had been attempted. Lipman and Conybeare (1936) reported 24.2 lb/A of nitrogen lost through erosion. Massey and Jackson (1952) reported nitrogen losses through erosion much higher than that reported by Lipman and Conybeare (1936). This emphasizes the difficulties encountered in making realistic assessments of nutrient losses through erosion.

Frevert et al. (1955) cited the findings of Moody (1948, unpublished) relating the quantity of nitrogen lost by erosion to the steepness of the slope. As the slope length and steepness increased, more soil was eroded, hence more nitrogen and other plant nutrients were lost. Stallings (1957) reported the following losses of nitrogen through erosion in a study conducted in 1939: Willamette Valley, Oregon, 29,000 tons of nitrogen annually; Tennessee River System, 23.8 lb/A of nitrogen a year; and the entire Mississippi River Basin, 6.64 lb/A of nitrogen per year. The same author reported that in Illinois, over a period of three years and eight months, 280.9 and 14.2 lb/A of nitrogen were lost by erosion from Muscatine and Cisne soils, respectively.

Using lysimeters, quantitative determinations of the amount of nitrogen leached had been reported by various workers under different cropping systems and rainfall intensity in various kinds of soils. Mooers et al. (1927) were among the early investigators who reported that leaching of nitrogen was greater from uncropped than from cropped soils. This was substantiated by the findings of Morgan and Jacobson (1942) and Chapman et al. (1949). The greater loss of applied nitrogen from uncropped soil is related to the amount of water that percolates through the profile. Allison (1965) and Black (1968) stated that when crops are grown, the amount of percolating water is considerably decreased due to increase in loss through evapo-transpiration. This situation may be especially true in soils of low permeability.

It had been reported that the amount of applied nitrogen lost through leaching varies with the kind of nitrogen-bearing material added. Morgan and Jacobson (1942) presented evidence of the influence of various forms of nitrogenous fertilizers on the amount of nitrate-nitrogen recovered from the leachate and the order of this loss was: sodium nitrate > calcium nitrate > potassium nitrate > ammonium sulfate > ammonium phosphate > calurea > calcium cyanamid > urea. These results indicated that the degree of leaching losses of nitrogen was related to the solubilization and adsorption properties of the various nitrogen sources.

Various studies concerned with leaching losses of nitrogen seem to emphasize three important considerations: (1) the downward movement of nitrate-nitrogen is more markedly influenced by percolation rate of water (and hence by structure of the soil) than by texture; (2) the amount of nitrate-nitrogen leached is highly dependent upon the concentration of nitrate in the soil at the instant water moves down; and (3) the quantity of nitrate-nitrogen moved down is affected by the balance between rainfall and consumptive use of water by plants. Some soils have structures that favor rapid infiltration rate of water even though their clay content is high. Shaw (1962) published evidence that more rainfall was required to leach out nitrate-nitrogen from the surface layer of light soils than from heavy soils and that more rain was needed to leach out the added nitrogen from the topsoil during summer than in winter. He attributed the causes of these striking results to: (1) even distribution of nitrate-nitrogen throughout the profile of the light soil on account of the granular structure whereas in the heavy soil there were vertical fissures through which water percolated rapidly, and (2) lower moisture in the soil profile in summer than in winter so that the infiltration rate was slower in the drier soil because of the entrapped air in the pores which blocked the entry of water.

It is obvious therefore that controlling leaching losses of nitrogen under field conditions can be effectively done only when water is furnished by irrigation. When the moisture supply is from natural precipitation alone, little can be done in minimizing leaching losses except through proper fertilization and crop management practices. Soubies *et al*. (1952) showed that when the nitrogen fertilizer applied was highly soluble, a 28.4-centimeter rainfall on fallowed sandy loam soil leached the nitrate-nitrogen out of the root zone.

Harvested Crops

The quantity of nitrogen lost through the harvested crop varies with the yield, kind of crop, and type of farming prevailing in the locality. Table I shows the amounts of nitrogen contained in different crops at harvest or maturity.

TABLE I

TOTAL NITROGEN IN VARIOUS CROPS AT HARVEST

Crop and author reporting	Yield	Total N (lb)
Field Crops		
Corn (Barber and Olson, 1968)	155 bu/A grain	98
	61 cwt/A stover	80
Grain sorghum (Tucker and Bennett, 1968)	5000 lb/A grain	85
	2.5 T/A stubble	50
Cotton (MacKenzie and vanSchaik, 1963)	3 bal/A	198[1]
Wheat (Olson and Koehler, 1968)	50 bu/A grain	63
	6000 lb/A straw	20
Barley (Olson and Koehler, 1968)	3000 lb/A grain	60
	4000 lb/A straw	14
Soybeans (Ohlrogge and Kamprath, 1968)	3000 lb/A seed	220[2]
	3500 lb/A straw	70[2]
	1500 lb/A stubble plus roots	35[2]
Forage Crops (Romaine, 1965)		
Alfalfa	6 T/A	335[3]
Clover-timothy	4.5 T/A	185[3]
Coastal bermudagrass	10 T/A	570
Orchardgrass	4.5 T/A	180
Johnsongrass (*Sorghum halepense*)	12 T/A	890
Vegetables (Lorentz and Bartz, 1968)		
Celery	1500 cwt/A tops	255[4]
	roots	25[4]
Lettuce	350 cwt/A	95[4]
Spinach	200 cwt/A	160[4]

Continued next page

TABLE I Continued:

Crop and author reporting	Yield		Total N (lb)
Potatoes	400 cwt/A	tubers	110[5]
		vines	40[5]
Tomatoes	600 cwt/A	fruit	170[5]
		vines	80[5]
Peas	70 cwt/A	peas	65[6]
		vines	70[6]
Persian melons	400 cwt/A	fruit	55[6]
		vines	80[6]
Brussels sprouts	160 cwt/A	sprouts	100
		other	85
Cantaloupes	225 cwt/A	fruit	50
		vines	40
Carrots	500 cwt/A	roots	55
		tops	65
Onions	400 cwt/A	bulbs	110
		tops	35
Snap beans	80 cwt/A	beans	120[7]
		plants	50[7]
Sweet corn	160 cwt/A	ears	55
		plants	70
Sweet potatoes	300 cwt/A	roots	75
		vines	40
Orchard (Reitz and Stiles, 1968)			
Oranges	630 cwt/A		88
Apples	880 cwt/A		32
Peaches (275 lb/tree, 108 trees/A)			68

Continued next page

TABLE I Continued:

Crop and author reporting	Yield	Total N (lb)
Sugarcane (Humbert and Ulrich, 1968)	13 T/A green leaves	25
	85 T/A millable cane	103
Rice (Mikkelson and Patrick, Jr., 1968)	4000 lb/A grain	60

[1]Includes 105 lb N contained in the seed of this crop.

[2]About 40 per cent of this is derived from the soil, the remainder, from fixed atmospheric N.

[3]About one-third to one-half of this comes from the soil, the remainder, from fixed atmospheric N.

[4]All removed from the soil.

[5]About one-third of this returned to the soil.

[6]About one-half of this returned to the soil.

[7]About one-third to one-half of this comes from the soil and the remainder, from fixed atmospheric N.

Nitrogen Transformations in Soils Leading to Its Loss

Depending upon microbial action and redox processes in the soil, nitrogen may undergo any of several transformations. The two end-products of these metamorphic processes are gases and nitrate nitrogen (Allison, 1965). Both of these end-results are easily lost from the root zone.

Nitrification. Although nitrification itself is not a direct pathway of nitrogen losses from soils, it is a contributory factor. Nitrate is readily leached. It is also rapidly denitrified to gaseous nitrogen under anaerobic conditions.

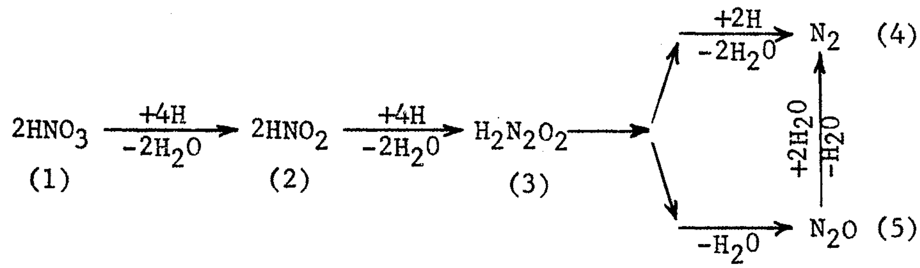
The nitrification rate in soils is influenced by several variables foremost of which are soil pH, temperature, and amount of nitrogen in the soil. Morrill and Dawson (1967) reported that pH had the most significant effect on nitrification rate in soils and showed different patterns of nitrification at various pH and soil types. These authors also noted that nitrification occurred substantially at pH 4.5 to 8.8 and that the nitrifying bacteria actively multiplied in this pH range.

Temperature exerts a considerable influence on the nitrification rate. Extremely low and high temperatures depress nitrate formation. However, several investigators, notably Tyler et al. (1959), Anderson (1960) and Overrein (1967) presented evidence that substantial nitrification could occur at 3 to 7 C. Harmsen and Kolenbrander (1965) published data showing that optimum nitrification occurred at 25 to 35 C. Incidentally, this is also the temperature range at which most field crops grow.

The effects of carbon and nitrogen on nitrification are related to the C:N ratio. Buckman and Brady (1969) contended that a high C:N ratio (>20:1) depresses nitrification because high carbon content in the soil promotes explosive microbial growth. The microbes utilize the nitrogen for physiological development instead of mineralizing it. When the ratio is lowered (<20:1) nitrification increases, according to these authors, because microbial population declines and more nitrogen is released in the soil.

Denitrification. The biological agents responsible for denitrification or gaseous transformation of nitrate in soils are some species of obligate as well as facultative anaerobes (Alexander, 1961). Denitrification happens when oxygen becomes highly limiting in the soil. Upon denitrification of nitrate, nitrogen may be lost to the atmosphere by volatilization as ammonia, nitric oxide, nitrogen dioxide, nitrous oxide, or nitrogen gas (Allison, 1965). Black (1968) analyzed the volatilized gases from microbial activities and found nitrous oxide and nitrogen gas.

Tisdale and Nelson (1968) postulated the following pathway for denitrification:



(1) Nitrate; (2) Nitrite; (3) Hyponitrous acid; (4) Nitrogen gas; and (5) Nitrous oxide.

The above diagram indicates nitrogen gas and nitrous oxide as possible end-products of this denitrification scheme. Waksman (1952) stated that the disappearance of nitrate from soils due to microbial action is caused by (1) direct use of nitrate as source of nitrogen when energy (carbon) material is sufficient, (2) conversion of nitrate to nitrite and ammonia in the process of nitrate assimilation, and (3) use of nitrates as a source of oxygen (hydrogen acceptor). The same author also postulated the following mechanisms of denitrification in soils:

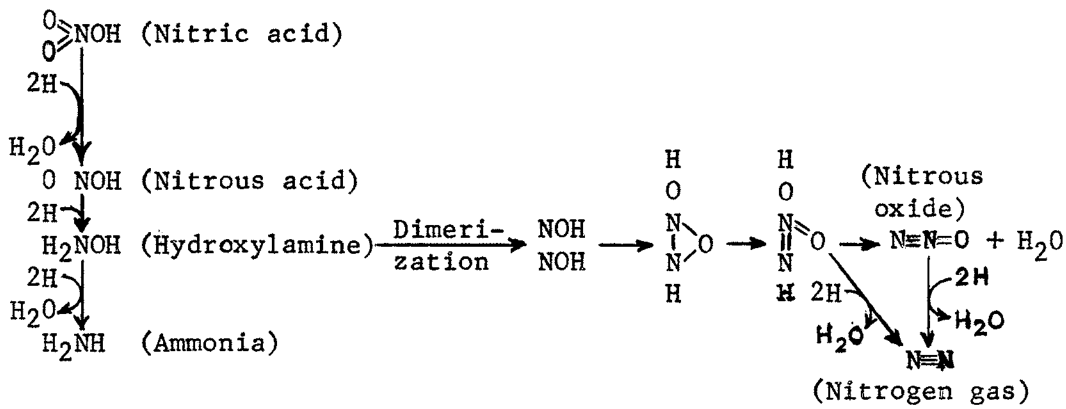
(1) $2HNO_3 \longrightarrow 2HNO_2 + O_2$, or $2HNO_3 \longrightarrow N_2 + 1\text{-}1/2O_2 + H_2O$.

(2) $2HNO_3 + H_2O \longrightarrow NH_3 + 2O_2$.

(3) In the presence of organic matter:

$$5C_6H_{12}O_6 + 24HNO_3 \longrightarrow 24H_2CO_3 + 6CO_2 + 18H_2O + 12N_2.$$

Scheme number two postulates ammonia as an end-product. This contention was bolstered by Bremner and Shaw (1958) who advanced the following pathway of nitrogen loss through denitrification:



Measuring the quantity of nitrogen from denitrification is difficult since it is influenced by so many variables. Tisdale and Nelson (1968) mentioned that these soil variables are pH, moisture level, partial oxygen pressure, nitrate concentration, and carbon content. Allison et al. (1960) observed that increasing the percentage of oxygen in the soil decreased the nitrogen loss by volatilization more markedly when no glucose was added. With the addition of 0.5 per cent glucose, the decrease in nitrogen loss with increasing oxygen content was still substantial but no longer marked.

Since denitrification occurs under anaerobic conditions, water saturation of the soil will hasten it. Ekpete and Cornfield (1966) noted that ammonia started to form at 50 per cent of the water holding capacity of the soil. Meek et al. (1970) presented evidence that maximum denitrification in a submerged soil in a column occurred at near saturation. The denitrification rate decreased at saturation and submergence. McGarity (1961) found that denitrification was greatly enhanced when the moisture content of the soil studied was increased from 8.7 to 20.5 per cent. This moisture range is generally below the field capacity of clay and clay loam soils so that it is highly possible that denitrification may be substantial in heavy soils even if the moisture content is only at or slightly below field capacity. Loewenstein (1957) reported a considerable loss of nitrogen through denitrification in a silt loam soil when moisture content was at field capacity. Allison (1955) showed that under anaerobic conditions and in the presence of *Bacterium denitrificans* and *Pseudomonas fluorescens* conversion of nitrate-nitrogen to nitrogen gas almost reached completion in two to three hours. This means that a few hours following a heavy rain and up to three days after when soils generally equilibrate at field capacity, denitrification could take place vigorously. Allison (1955) stated further that even under aerobic conditions denitrification in heavy soils could take place in localized spots when the micropores are filled with water even if the macropores are aerated.

Differential losses of gaseous nitrogen from various sources had been investigated. Wagner and Smith (1958) listed this order of such losses: urea > ammonium nitrate > aqua ammonia > ammonium sulfate = sodium nitrate in clay, silt loam and fine sand soils although the gaseous losses were higher in heavier soils than in the lighter ones. This order of gaseous losses appears to be the reverse of the order of leaching losses of nitrogen reported by Morgan and Jacobson (1942) insofar as urea and sodium nitrate are concerned. Apparently, much of the loss from urea was in the form of ammonia. Wahhab *et al*. (1960) noted that *Micrococcus ureae* and *urobacilli*, under acidic conditions, excrete the enzyme urease which hydrolyzes urea to ammonium carbonate. The ammonium carbonate readily decomposes to ammonia, carbon dioxide and water. This was substantiated by the findings of Overrein (1967) who reported that ammonia was volatilized even from acidic forest humus.

Nitrogen volatilization through chemical reactions. Under alkaline conditions losses of applied nitrogen through volatilization as ammonia by chemical reaction may be substantial. The mechanism involved had been postulated by Tisdale and Nelson (1968) as follows:

$$NH_4^+ + H_2O + OH^- \longrightarrow NH_3 + 2H_2O.$$

Clark et al. (1960) reported that loss of nitrogen from urea was greater in initially alkaline and poorly buffered soils. Allison (1966) and Meyer et al. (1961) also stated that ammonia volatilization from alkaline soils is aggravated by drought and low cation exchange capacity of the soil.

Other variables aside from high pH, low buffering capacity, low cation exchange capacity and low moisture content of soils also affect the volatilization of ammonia. Ernst and Massey (1960) observed that volatilization of ammonia from urea increased with decreasing depth of application. These authors also stated that another possible cause of ammonia volatilization at high pH is that Ca^{++} competes more strongly than NH_4^+ in the adsorption sites of clays when the reaction is alkaline, thus more NH_4^+ is released into solution which reacts with H_2O and OH^- to form ammonia.

Disproportionate dismutation reactions or spontaneous decomposition of nitrite to nitric oxide and nitrogen gas. Aside from nitric oxide and nitrogen gas production through biological means, purely chemical reactions involving the dismutation reactions or decomposition of nitrites occur in soils. Loss of nitrogen through this means occurs in well-drained and acidic conditions (Tisdale and Nelson, 1968). These authors classified nitrogen loss from soils in this way into three categories:

1. Spontaneous decomposition of ammonium nitrite:

   $NH_4NO_2 \longrightarrow 2H_2O + N_2$.

2. Van Slyke reaction:

   $RNH_2 + HNO_2 \longrightarrow ROH + H_2O + N_2$.

3. Spontaneous decomposition of nitrous acid:

   $3HNO_2 \longrightarrow 2NO + HNO_3 + H_2O$.

Allison (1955) supported the foregoing concepts of nitrogen loss through chemical reactions. Nelson (1967) contended that the organic soil constituents are largely responsible for the reduction of nitrite to nitrogen gas and nitrous oxide thus supporting the Van Slyke reaction concept.

When anhydrous ammonia or urea is added to soils, accumulation of high amounts of ammonium, as a consequence of slow nitrification rate following ammonification, may occur. Under this condition, nitrogen gas may be lost to the atmosphere through the reaction with nitrites. Clark _et al_. (1960) and Sabbe and Reed (1964) reported that nitrogen gas volatilization involving the reaction of ammonia with nitrite is indeed possible as follows:

$NH_3 + HNO_2 \longrightarrow N_2 + 2H_2O$.

Reduction of nitrate to nitric oxide, nitrous oxide, and nitrogen gas by reducing compounds in the soil. Soils contain reducing agents such as sulfur and other metals. When nitrates come in contact with these reducers, a possibility may occur that the nitrates are reduced to gaseous forms. Chao (1967) showed that from thermodynamic point of view, there is a probability that nitrate is reduced by sulfur compounds of low oxidation states to nitric oxide, nitrous oxide, and nitrogen gas. Wullstein (1967) contended that metallic complexes in soils could transform soil ammonium and nitrate to nitrous oxide and nitrogen via redox processes. However, conclusive evidence of gaseous losses of nitrogen by reducing compounds in soils is still lacking.

Nitrogen Immobilization in Soils

It has long been known that nitrogen in soils is immobilized through bio- and physico-chemical processes. Although nitrogen immobilized this way is not lost from the soil, it is not readily available to plants. More and more evidence has been presented in the literature supporting the contention that nitrogen immobilization in soils could be significant.

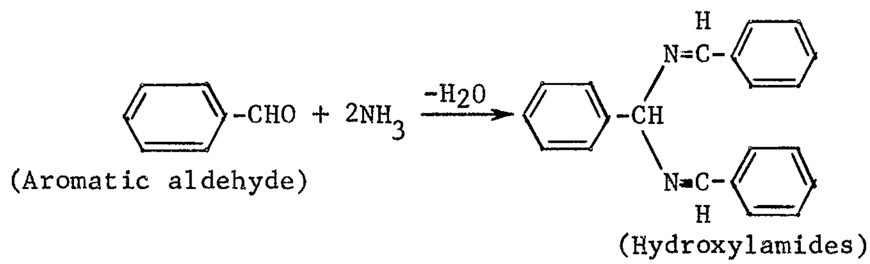
Biological Immobilization of Nitrogen in Soils

A number of species of soil microbes (fungi and bacteria) assimilate nitrogen for cellular development. The assimilated nitrogen is incorporated into protein substances and thus becomes unavailable to crops until the microbes die and the cellular components decompose. This temporary unavailability of nitrogen is termed biological immobilization to distinguish it from nitrogen immobilization in soils caused by physico-chemical reactions.

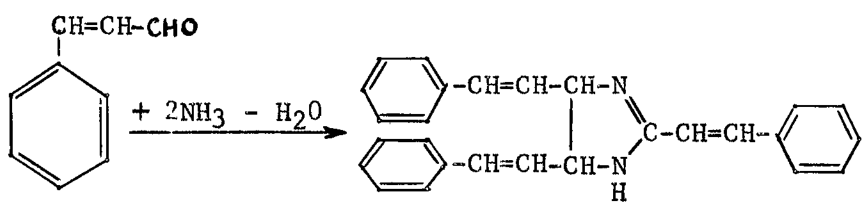
Immobilization of nitrogen by microbes is greatly influenced by the C:N ratio and this had been discussed previously under the subsection Nitrification on page 8.

Nitrogen Immobilization by Organic Matter

Apart from biological immobilization of nitrogen by assimilation, nitrogen in soils is also rendered slowly available to plants through fixation by organic matter in the soil. Sprung (1940) hypothesized the immobilization of ammonia by organic matter in the following pathways:



or



Broadbent et al. (1958) made the observation that the phenolic compounds mentioned by Sprung (1940) must undergo partial oxidation before ammonia fixation can occur and that these active groups are possibly quinones produced by oxidation of polyphenols. The same investigators also noted that (1) linear and direct relationship occurred between the amount of ammonia immobilized and the per cent carbon in the soil and (2) a logarithmic pattern of increasing ammonia fixation with increasing pH.

When nitrogen is fixed by organic matter its release is relatively slow. Bremner and Fuhr (1963) also reported that only 55 to 60 per cent of the immobilized nitrogen was released by boiling the soil with 6N hydrochloric acid for 12 hours. This was substantiated by Broadbent and Nakashima (1967) who indicated that it took longer and longer time required to mineralize one per cent of ^{15}N that reverted to organic matter as the number of cuttings of sudangrass increased. This means that the longer the reverted form of nitrogen stays in the soil, the more difficult it is to mineralize.

Immobilization of Nitrogen by Potassium, Phosphorus, and Aluminum in Soils

In humid and warm areas of the world, there is a great likelihood that nitrogen is immobilized in soils by potassium, phosphorus and aluminum. This is because in these regions heavy fertilization of nitrogen, phosphorus and potassium is often practiced in soils containing high amounts of aluminum. Kanehiro et al. (1960) noted that sorption of ammonium was higher in latosolic soils when applied as $NH_4H_2PO_4$ or $(NH_4)_2HPO_4$ than when applied as $(NH_4)_2SO_4$ or NH_4Cl. This seems to indicate that some insoluble compounds, e. g. nitrogen, phosphorus, potassium and others form in the soil. The findings of Tamimi et al. (1963) substantiated this when they identified the highly insoluble ammonium taranakite $[H_6(NH_4)_3Al_5(PO_4)_8 \cdot 18H_2O]$ by X-ray diffraction of Hydrol Humic and Humic Latosols treated with high ammonium and phosphate, and allowed to stand for several weeks under room temperature.

Ammonium Fixation by 2:1 Clay Minerals

Immobilization of applied nitrogen in the crystal lattice of 2:1 clay minerals has been a subject of considerable study. A mass of evidence obtained by various methods and workers have been reported in the literature.

The geometry of the spaces between two adjacent tetrahedral layers of 2:1 clays allows for some ions of certain radius (2.89 A) to fit in (Page and Baver, 1939). The K^+ and NH_4^+ ions have a radius almost the same as this one, thus they fit easily into the spaces between the tetrahedral layers of 2:1 clays.

When NH_4^+ is fixed in the crystal lattice of clays, it is not readily available to plants. Bower (1951) found only minute amounts of fixed NH_4^+ recovered by barley seedlings grown for 17 days (using the modified Neubauer technique). The amounts recovered were too low to sustain the barley if it were to depend upon the fixed NH_4^+ alone for nitrogen nutrition.

Montmorillonitic minerals, especially the micas, are known to fix substantial amounts of NH_4^+. Mikami and Kanehiro (1968) obtained varying amounts of native fixed ammonium-nitrogen in various Hawaiian soils ranging from zero to 33 per cent of the total native nitrogen. Legg and Allison (1961) obtained increasing amounts of immobilized ^{15}N in two soils with increasing ^{15}N added.

The massive data presented in the literature about ammonium fixation indicate that the quantity of ammonium-nitrogen immobilized in the crystal lattice of the minerals varies with the specific surface of the clay (2:1 has greater specific surface than 1:1 clays), kind and concentration of cations associated with NH_4^+, temperature, moisture content of the soil, concentration of NH_4^+ in solution, the amount of hydroxyaluminum groups in the soil, and intensity of cultivation and phosphate fertilization (Nomik, 1965). Potassium competes for ammonium fixation in clays. Therefore, the presence of this cation in substantial quantities in the soil could decrease ammonium fixation. Increasing temperature within the range of zero to 60 C increases ammonium fixation (Nomik, 1957). Dry soils fix more ammonium than moist soils, due in part to the penetration of ammonia into the lattice. Alternate drying and wetting increases ammonium fixation of soils as reported by Nomik (1965). The same author stated that intense cultivation and phosphate fertilization increases ammonium fixation in soils. He also contended that the hydroxyaluminum groups have been found to increase the release of fixed ammonium due to "propping" effect. (These groups prevent collapsing of the lattices of clays thus allowing larger "openings" between lattices for ammonium to escape.) The effect of ammonium concentration in solution on the amount of ammonium fixed in the lattices has been represented by Nomik (1957) in the following equation:

$$NH_4 \text{ sol'n} \rightleftharpoons NH_4 \text{ exch.} \rightleftharpoons NH_4 \text{ fixed}$$

Thus if the concentration of ammonium in solution is increased, the equilibrium shifts to the right and vice versa.

CHAPTER III

MATERIALS AND METHODS

Urea and ammonium nitrate were the two nitrogen carriers involved in this study. Field experiments, greenhouse bioassay and laboratory studies were conducted.

Field Experiments

The crops grown in the field plots were grain and forage sorghums, bermudagrass and cotton. Five soil types at five different locations in Oklahoma were used.

Grain sorghum

Four experiments were conducted on grain sorghum at three locations in Oklahoma over two cropping seasons, 1968 and 1969. In all locations the grain sorghum was planted with a two-row rear-mounted planter.

Mangum. The field experiment at Mangum involved a Meno loamy fine sand with a compact layer of low permeability at a depth of 18 to 24 inches. The design was randomized complete block replicated four times, using 20- x 60-foot plots, each containing six 40-inch rows. The two middle rows were harvested for yield. The variety used in both seasons was OK 612. Three variables were studied in a factorial arrangement: (1) sources of nitrogen; (2) rates of nitrogen applied

(0, 30, 60 and 90 lb/A); and (3) the length of exposure (0, 24 and 48 hours) of the nitrogen fertilizer before covering them. All the plots received 60 lb/A P and 50 lb/A K. The fertilizers were hand-banded on shallow furrows 2 to 3 inches away from the two-week old sorghum plants. The sorghum was planted on June 20 in 1968 and harvested on November 20. In 1969 it was planted on June 22 and harvested on November 22.

Perkins. Two trials were conducted at Perkins on a Vanoss silt loam in two seasons, 1968 and 1969. Experiment I consisted of differential rates of urea and ammonium nitrate at 0, 50, 100 and 150 lb/A N. The fertilizers were applied by using a custom-built two-row rotating cone fertilizer distributor attached to a two-row planter. The experimental design, plot size, row spacing, sampling procedure, and replications were the same as those at Mangum. In 1968 at Perkins OK 612 variety of grain sorghum was used. In 1969 a "bird-resistant" variety AKS 614 was planted to minimize bird damage. Uniform applications of 19.5 lb/A P and 16.5 lb/A K were made on all plots.

Experiment II consisted of two exposure periods of one rate of nitrogen (50 lb/A) from both nitrogenous fertilizers. The exposures were 0 and 72 hours. The fertilizer application and covering of the exposed fertilizer treatment were the same as in Mangum. At Perkins, each plot consisted of five 40-inch rows 30 feet long and the middle row was harvested for yield. In 1968 the experimental design was completely randomized in nine replications, using variety OK 612. In 1969 the design was randomized complete block replicated five times, using variety AKS 614. The P and K rates applied to all plots were the same as in Experiment I.

In 1968 the sorghum was planted on both experiments on June 20 and harvested on October 25. In 1969 it was planted on July 3 and harvested on November 18.

Muskogee. In Muskogee grain and forage sorghums were planted on Taloka silt loam. In both crops a split-plot in a randomized complete block design was used. The main plots consisted of various N-P-K combinations while the sub-plots were the two sources of nitrogen. The N-P-K combinations in the main plots were: 0-26.4-16.6; 40-26.4-16.6; 80-26.4-16.6; 120-26.4-16.6; 80-0-16.6; 80-13.2-16.6; 80-39.6-16.6; 80-26.4-0; 80-26.4-33.2; 120-39.6-0; and 120-39.6-33.2.

The fertilizer applicator, plot size, row spacing, and sampling for both crops were the same as those of Experiment I at Perkins. In 1968 OK 612 and Sugar Drip varieties were planted on June 3. The 1968 grain sorghum was harvested on October 7 and the forage sorghum was sampled on October 7 also. In 1969 AKS 614 was planted on June 13 and harvested on November 8 while Sugar Drip forage sorghum was planted on June 20 and sampled on November 12. Fresh forage samples were weighed and then oven-dried.

Bermudagrass

The field plot trial on bermudagrass was at Stillwater on a Port loam. The experimental design was randomized complete block with four replications on a plot 12 feet x 30 feet. The experimental area was on an old bermudagrass experiment. The grass was renovated in summer of 1968 by clipping and then applying 100 lb/A nitrogen from ammonium nitrate, using a six-foot grain drill calibrated as a fertilizer spreader. In the summer of 1969 the grass was mowed close to the ground and then the plots laid out to accommodate a factorial arrangement of two nitrogen sources at four rates of application (0, 100, 200 and 400 lb/A). All rates above zero were applied only once in the same morning on June 28. Uniform applications of P and K at 26.6 and 33.2 lb/A, respectively, were made on all plots. Sampling was made with a "Jari" mower, clipping a 3- x 6-foot area. The fresh samples were weighed and then oven-dried. The first clipping was on July 31 or 33 days after fertilization while the second clipping was on September 20 or 50 days after the first.

Total N in the grain and forage sorghums and in bermudagrass was determined by micro-kjeldahl method. Total P was colorimetrically determined by using Jackson's (1958) vanadomolybdophosphoric acid yellow color method. The turbidimetric method of Chesnin and Yien (1950) was used for total sulfur. Total K, Ca, Mg and Na were determined with an atomic absorption spectrophotometer.

Cotton

The cotton experiment was on irrigated Hollister silty clay loam at Altus. The fertilizer applicator, experimental design, plot size and row spacing were the same as those of Experiment I at Perkins. Three replications were provided in a factorial arrangement of two variables: one was the nitrogen sources and the other was the rates of nitrogen (0, 50, 100, 150 and 200 lb/A). Blanket applications of 26.6 lb/A P and 33.2 lb/A K were placed on all plots. The cotton was planted on May 24. The first harvest was on November 20 and the second, on December 22.

Greenhouse Tests

Studies on urea and ammonium nitrate were conducted in the greenhouse using surface soil of Taloka silt loam (except Experiment IV) from Muskogee. Five experiments were done. Size 10 cans of one-gallon capacity were used for Experiments I to IV and 14-gallon stainless steel cans were used for Experiment V. All experiments, except IV which was replicated five times, had three replications. The experimental design for all five experiments was a randomized complete block.

Experiment I

Experiment I was a comparative study of the effects of urea and ammonium nitrate on the yield of Piper sudangrass. The nitrogen rates from both sources were 0, 60, and 120 lb/A and the fertilizers were dissolved in water and then mixed thoroughly with the soil. Blanket applications of 60 lb/A P and 80 lb/A K were made on all pots. Each can was lined with polyethylene bag and contained 2.75 kg air dry soil. The seeds were planted 10 to 15 per can on September 3, 1968 and then thinned on September 10 to five plants per can. The plants (above ground parts) were harvested on October 17, weighed, and then oven-dried.

Experiment II

In Experiment II urea was also used as the source of nitrogen at rates of 0, 60 and 120 lb/A, concentrated superphosphate at 0 and 50 lb/A P, and tannic acid (digallic acid with 57 per cent tannic acid from Fisher Company) at 0, 8.5 and 17.0 lb/A. K was uniformly applied to all pots at 80 lb/A. The plant indicator, soil weight per can, fertilizer, planting, thinning, and harvesting were the same as those of Experiment I (greenhouse).

Experiment III

The third study was on the effects of urea and ammonium nitrate and tannic acid on the dry matter yield of rice. Three kg of air dry soil were used per can. The factorial arrangement was: 2 N sources, 2 moisture levels (submerged and "field capacity"), 3 N rates (0, 60 and 120 lb/A), and 3 tannic acid rates (0, 11.5 and 23.0 lb/A). Blanket applications of 80 lb/A P and 60 lb/A K were made on all cans. The dry powdered fertilizers and tannic acid were mixed with the upper third of the soil in the can. The rice variety used was Saturn from Crowley, Louisiana. The seeds were planted five to a can on September 3, 1969, the plants thinned to 2 per can on September 10, and the first sampling was on October 22 (6 weeks old). The second and final sampling was on November 22 (10 weeks old). The fresh weight was taken and the samples were oven-dried.

Experiment IV

In this experiment, the soil used was Spur fine sandy loam from Hammond, Oklahoma. Five replications were provided in a randomized complete block design with two N carriers (urea and ammonium nitrate) and two moisture levels. Seeds of sorghum-sudangrass hybrid (Sudax) were planted on September 28, 1970 at the rate of 15 to 20 seeds per can, and the seedlings were thinned to 10 plants per can on October 3.

The moisture scheme involved saturating three of the five replications when the plants were three weeks old. The remaining two replicate pots were not saturated at this stage of growth but the moisture was maintained at "field capacity" as in the beginning of the experiment. The saturated condition of the three pots was maintained for two days to allow reducing processes to proceed in the soil. After two days, saturation was discontinued and the moisture condition allowed to revert to about "field capacity" through evapo-transpiration and this condition was attained in about three days.

Sampling of plants was made before and after saturation. Close observations for chlorosis were made on the submerged pots and on the pots at "field capacity."

Experiment V

In this experiment 70 kg air dry soil per can was used with two N sources at 0 and 100 lb/A. P and K at 44 lb/A and 83 lb/A, respectively, were uniformly applied to all cans one week before transplanting. The fertilizers were applied on the soil surface which was then submerged in water. The soil used was Taloka silt loam from Muskogee.

The soil in the can was surmberged for 72 hours before transplanting the rice seedlings. The rice seeds, variety IR 8 from the University of Arkansas Rice Research Station, were broadcast on sandy soil on September 8, 1970 and 30 seedlings were transplanted to each can on September 27. Water in the cans was maintained at 2-1/4 inches above the soil through a reservoir-siphon system shown in Figure 1.

The redox potential for each treatment was periodically taken at 2, 4, 6 and 10 cm deep in the soil until booting stage. The method

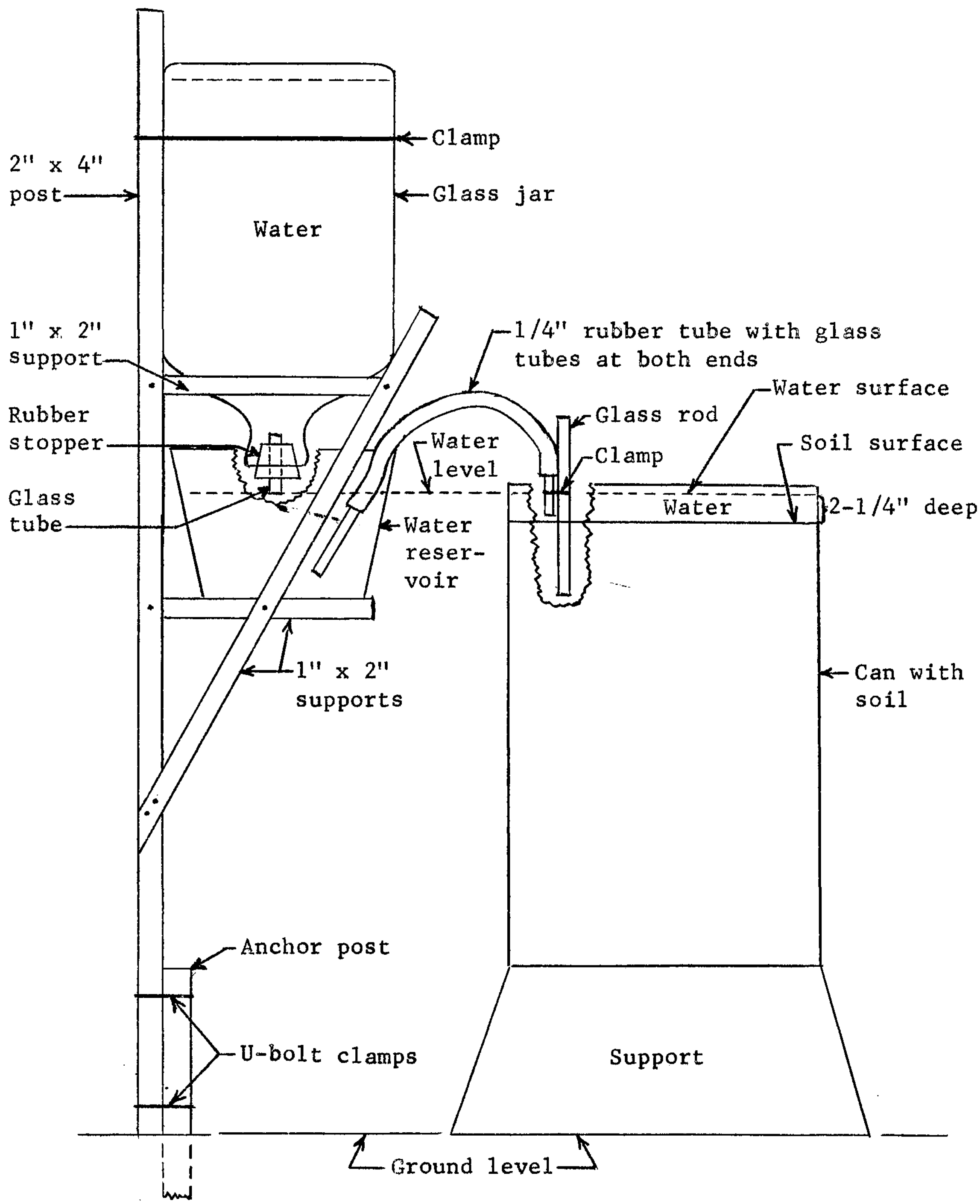


Figure 1. Schematic Diagram of the Reservoir-Siphon System Used to Maintain a Constant Head for Submerged Soil

used in redox potential measurement was that of Jackson (1956). Samplings of four plants per can were made immediately after each redox potential measurement. The plant samples did not include the roots.

Laboratory Experiments

Two laboratory studies were included in these investigations: N release from, and leaching of urea and ammonium nitrate. Two soils were used for the N release (Taloka silt loam and Brewer clay loam), and five for N leaching (Port loam, Vanoss silt loam, Taloka silt loam, Tipton clay and Hollister silty clay loam).

Nitrogen Release Study

The release of N from urea and ammonium nitrate was studied using a silt loam (Taloka) and clay loam (Brewer) soils. The factorial arrangement of the treatments was: 2 N sources (urea and ammonium nitrate); 2 soils (Taloka silt loam from 0 to 6 inches depth and Brewer clay loam from 8 to 12 inches depth); 3 moisture levels ("field capacity," saturated, and submerged); 4 incubation periods (5, 10, 20 and 40 days); and 3 replications for each treatment combination. N from both sources was applied at 100 ppm to 10 g of air dried soil ground and passed through a 200-mesh sieve and placed into 50-ml Erlenmeyer flask. After the N application the moisture was brought to the desired level and the flask left exposed but protected from air contaminants. The moisture levels were determined in the following manner: saturation of the sample was made using the procedure in USDA Handbook No. 60 (1954) and "field capacity" was considered half of the water added to bring the soil to saturation point. For the submerged sample, the water added was twice the amount for saturation. After the desired moisture level was reached the flask was weighed and daily addition of water, when necessary, was made to maintain the moisture content of the soil. At the end of the incubation period, the soil in the flask was shaken with a total of 25 ml water added and NH_4- and NO_3-N determined from the water extract. Residual urea was analyzed from the urea-treated samples using the following colorimetric method:[1]

One ml extract placed in clean test tube and 1 ml 10 per cent urease solution added. Let stand 1 hour, add 3 drops 10 per cent tartrate solution, 2.5 ml water, and 0.5 ml Nessler solution. Mix well, let stand 15 minutes and then read at 430 mu in the colorimeter. Calculate urea NH_3 by subtracting "extractable" NH_3 of same soil sample.

Ammonium fixation by each soil was determined by shaking 50 ppm NH_4-N with 10 g soil sample in 25 ml water and analyzing the supernatant for remaining NH_4-N. The water-extractable NH_4-N of the two soils at each incubation period was corrected for the amount of NH_4 fixed.

Analysis of the NH_4- and NO_3-N in the water extract at each incubation period was made using the procedures in the Soil Fertility laboratory at the Department of Agronomy, Oklahoma State University. These procedures are as follows:

Nitrate (Modified Phenoldisulphonic) Method

Reagents:

1. Phenoldisulphonic Acid. Dissolve 100 g of pure white phenol in 600 ml of 96 per cent sulfuric acid. Add

[1]Mimeographed procedure in Advanced Soil Biology course at the Department of Agronomy, Oklahoma State University taught by Dr. J. Q. Lynd.

300 ml fuming sulfuric acid. Heat at 100 C for two hours.

2. Sodium Hydroxide-Versene (EDTA), 12 N. Dissolve 480 g of sodium hydroxide in 600-700 ml of distilled water and allow to cool. Dissolve 20 g of EDTA in about 200 ml water. When the sodium hydroxide is cool, add the solution of EDTA and make to one liter.

3. Sodium Hydroxide, 1 N. Dissolve 40 g of sodium hydroxide in one liter of distilled water.

Procedure:

Pipette a suitable aliquot of solution into a 50 ml beaker. Add a small amount of sodium hydroxide to make sure the solution is alkaline to phenolphthalein and evaporate to dryness. When evaporation is complete, allow the beaker to cool, then add 2.0 ml of phenoldisulphonic acid using a bulb-type automatic pipette. The beaker should be rotated to make sure that the acid comes in contact with all the residue. Allow the acid to react for at least 10 minutes, then add 25 ml of water and stir. Add 10 ml of 12 N sodium hydroxide-EDTA reagent and stir. Allow to cool and read at 420 mu against a blank of distilled water.

Ammonia (Modified Nessler) Method

Reagents:

1. Nessler Reagent. Add 30 g of A. C. S. reagent grade metallic mercury to a solution of 22.5 g of iodine and and 30 g of potassium iodide in 20 ml of water in a glass-stoppered pyrex bottle. Cool the mixture in water. Shake the mixture mechanically for an hour and filter through a sintered-glass funnel. Bring the volume to 200 ml with water and add this solution to 975 ml of 2.3 M carbonate-free sodium hydroxide.

2. Restoring Solution. Dissolve 7.5 g of potassium iodide and 5.6 g of iodide in 100 ml of water.

Procedure:

Place an aliquot of the sample to be determined in a test tube. Add water to bring the volume to 4.0 ml. Cool the solution and the Nessler reagent to 18-20 C. Add 1.0 ml of the Nessler reagent while the test tube is still in the water bath. Allow the color to develop for 2-3 minutes. Read the optical density at 430 mu against distilled water blank. The highest standard should contain 22 ug of NH_3-N.

Leaching Study

Undisturbed soil cores from 0 to 48 inches deep were obtained from different locations with a hydraulic soil probe attached to the power-take-off of a 50-horsepower Ford tractor. Core samples were taken from the check plots of the field experiments on grain and forage sorghums at Muskogee, grain sorghum at Perkins, bermudagrass at Stillwater and cotton at Altus. A cotton experimental plot at Tipton was also sampled. The soil cores were stored and air-dried in mailing tubes made of cardboard. The outside diameter of each core was 2.663 inches when taken from the field.

For leaching studies, the air dry cores were transferred to transparent plexiglass cylinders which had been split lengthwise into halves. The plexiglass seams were sealed with masking tape and the whole cylinder with the soil core in it was bound tight with screw clamps and then weighed. The clamped cylinder was made to stand upright near the reservoir-siphon system shown in Figure 1. One column from each location received 100 lb/A N as urea and another column, with 100 lb/A N as ammonium nitrate. The fertilizer was placed on the soil at the top of the column and a constant-head of four inches of water was maintained over the soil after the fertilizer was applied. Water was allowed to percolate down the column until it approached just slightly above (about 1 to 2 inches) the 48-inch depth. At the end of the percolation period, the core was segmented into three-inch sections, weighed, and then air-dried. The content of NH_4- and NO_3-N was determined by section using the modified Nessler and phenoldisulphonic methods mentioned earlier, and one hour shaking of 10 g of air dry sample (ground to pass 200-mesh sieve) in 25 ml of 1.5 N KCl.

From the field plots of the bermudagrass experiment on Port loam at Stillwater, profile samples were taken at four-inch depth increments down to 48 inches. Three replications from all nitrogen levels of urea and ammonium nitrate plots were sampled. NH_4- and NO_3-N was determined on these samples in the same manner as the undisturbed cores.

CHAPTER IV

RESULTS AND DISCUSSION

Field Experiments

Grain Sorghum

Urea and ammonium nitrate were compared as regards their effects on the yield and nutrient uptake of grain sorghum. The effects of both nitrogen (N) carriers on uptake of other nutrients by grain sorghum was studied only at Muskogee on Taloka silt loam where N was applied in combination with various rates of phosphorus (P) and potassium (K).

Mangum. The 1968 yields of grain sorghum OK 612 on Meno loamy fine sand at Mangum are shown in Figure 2 and Table II. The yield data in 1969 may have been biased by worm infestation. Therefore, they are not reported. The monthly rainfall for the cropping seasons at Mangum and the other locations is indicated in Table III.

The analysis of variance of the 1968 yield of OK 612 grain sorghum at Mangum (Table II) on Meno loamy fine sand shows no significant differences between urea and ammonium nitrate and exposure periods. However, there was a significant difference at 5% level in yields between rates of N. This significant difference in yields was between 30 lb/A N at 0 hour exposure and 60 lb/A N at 48 hours exposure of ammonium nitrate. The mean yields from the other rates of both sources of N were not significantly different from each other.

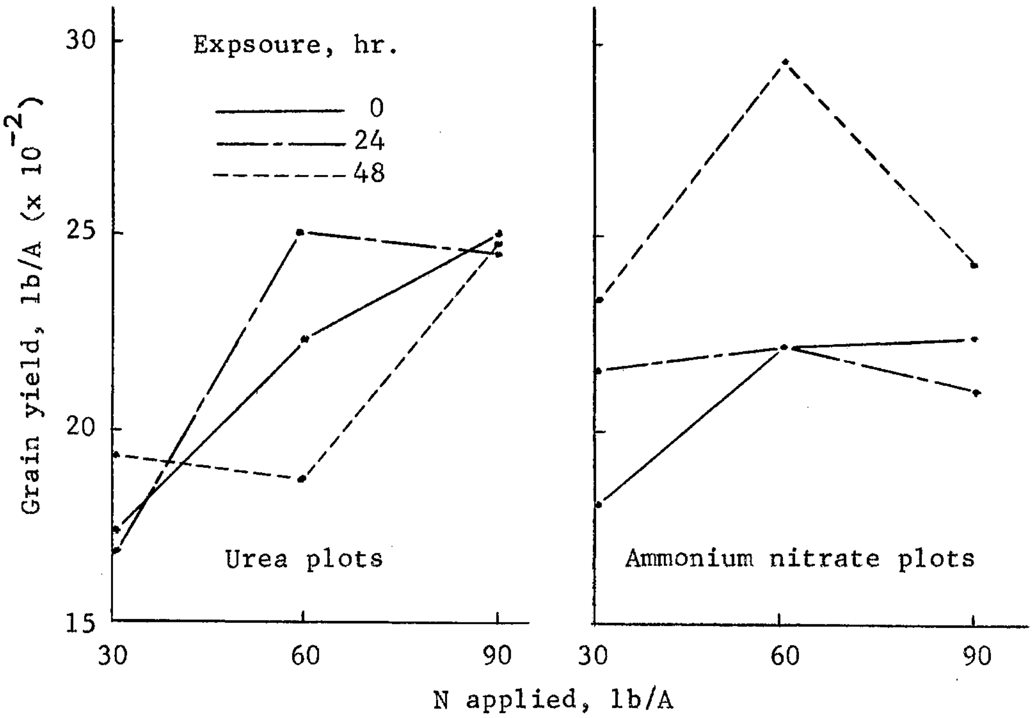


Figure 2. The Effects of Urea and Ammonium Nitrate on the Grain Yield of OK 612 Sorghum on Meno Loamy Fine Sand at Mangum in 1968. Values are Means of Four Replications

Perkins. Two experiments were conducted on Vanoss silt loam at Perkins. In Experiment I (Figure 3, top and Table IV) several rates of urea and ammonium nitrate were used while in Experiment II (Figure 3, bottom and Table IV) 50 lb/A of N was applied as urea and ammonium nitrate with exposure periods of 0 and 72 hours. In Figure 3 the 1968 data are at the left (top and bottom) while the 1969 data are at the right, top and bottom.

1. Experiment I. The yield responses of grain sorghum to urea and ammonium nitrate on Vanoss silt loam were not significantly different from each other at all rates. The apparent high variability among plots of this experiment in 1969 masked differences in treatment

TABLE II

ANALYSES OF VARIANCE, MEAN YIELDS AND LEAST SIGNIFICANT RANGE (LSR) VALUES OF THE EXPERIMENTAL DATA FOR GRAIN SORGHUM ON MENO LOAMY FINE SAND AT MANGUM

Source of variation	df	Mean square[1]
Blocks	3	49.9211
N sources (N)	1	10.7323
N rates (R)	2	74.2002*
Exposure (E)	2	17.8105
N x R	2	29.8510
N x E	2	38.4023
R x E	4	3.0920
N x R x E	4	22.7701
Error	51	20.0603
C. V.		27.55%

Mean yields (lb/plot) at various N rates

	N rate (lb/A)								
	30			60			90		
Exposure (hr.)	0	24	48	0	24	48	0	24	48
Urea plots	13.2	13.0	14.7	17.2	19.2	14.4	19.2	18.9	19.0
Ammonium nitrate plots	13.8	16.8	18.0	17.1	17.1	22.7	17.2	16.2	18.6

LSR Values

No. of pairs	2	3	4	5	6	7	8	9
LSR (5%)	6.4	6.7	6.9	7.0	7.2	7.2	7.4	7.4

[1]Analysis of yields was on lb/plot.
*Significant at 5% level.

TABLE III

THE MONTHLY RAINFALL (INCHES) IN 1968 AND 1969 AT THE FIVE EXPERIMENTAL LOCATIONS IN OKLAHOMA

Month	Locations				
	Mangum	Altus	Muskogee	Perkins	Stillwater
			1968*		
January	2.03		4.64	1.75	
February	1.69		0.66	0.28	
March	1.09		5.11	3.76	
April	1.27		3.94	2.27	
May	5.69		7.65	4.13	
June	3.60		3.76	1.79	
July	2.41		1.17	0.82	
August	3.07		4.64	1.81	
September	0.85		3.38	2.01	
October	3.95		2.16	1.87	
November	2.93		6.54	4.59	
December	0.86		2.52	1.97	
1968 total	29.46		46.17	27.05	
			1969		
January	Trace	0	3.91	0.27	0.75
February	1.91	1.64	3.43	2.28	2.27
March	2.11	1.58	3.76	2.37	2.60
April	0.39	0.27	3.45	2.67	1.93
May	5.71	5.91	4.40	2.73	3.60
June	3.00	1.75	2.76	5.00	4.43
July	3.28	2.31	0.43	1.63	1.43
August	2.02	3.26	1.68	2.96	3.11
September	4.09	4.31	1.04	4.94	3.77
October	1.99	2.09	9.09	3.42	2.63
November	0.22	0.36	0.84	0.11	0.08
December	0.28	0.43	2.84	1.47	1.24
1969 total	25.00	23.91	37.63	29.85	27.84

*No rainfall data were taken in 1968 at Altus and Stillwater since there were no experimental crops grown in these locations during that season.

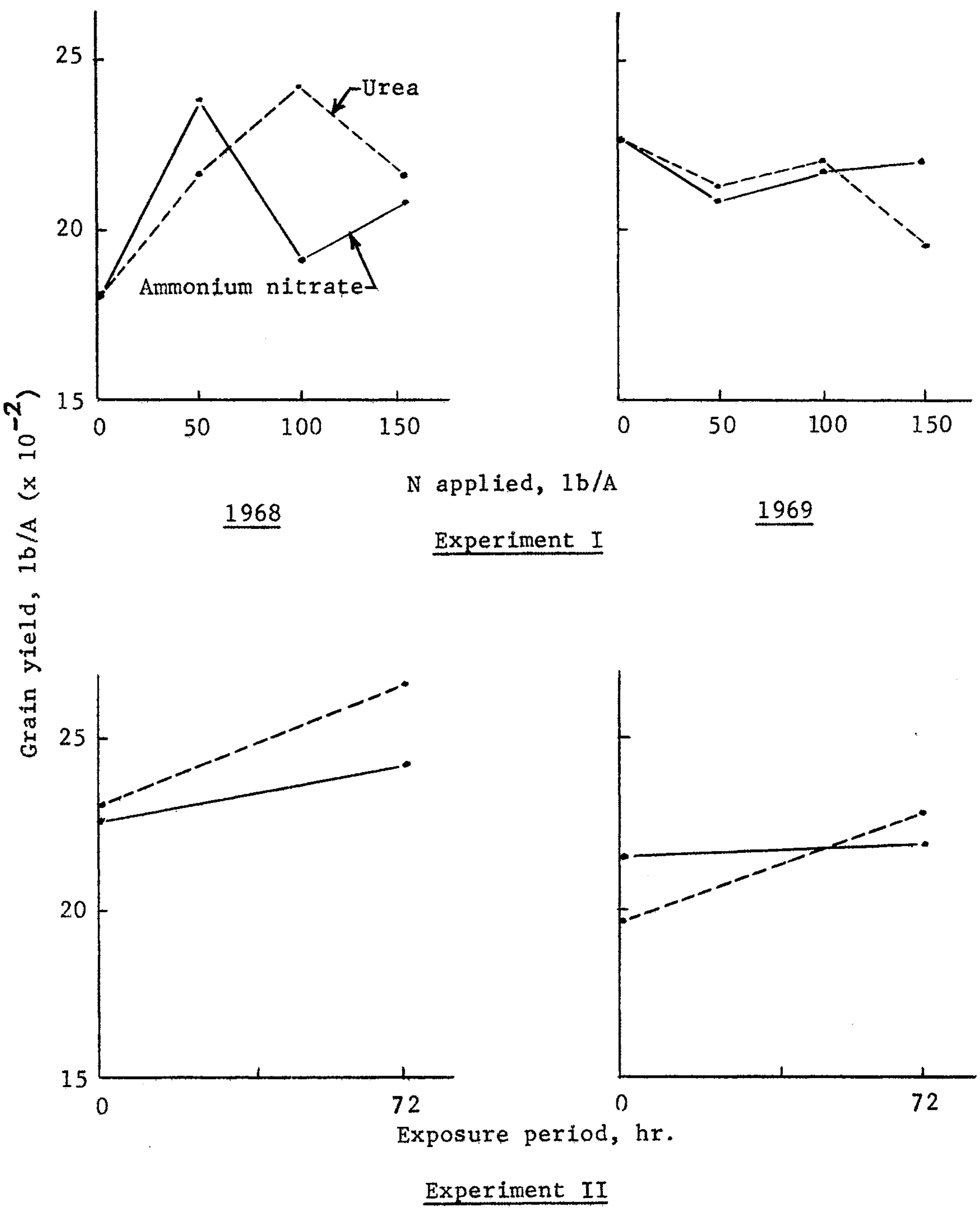


Figure 3. Yields of Grain Sorghum in Two Experiments on Vanoss Silt Loam at Perkins in 1968 (Left, Variety OK 612) and 1969 (Right, Variety AKS 614). In Experiment I (Top) Values are Means of Four Replications. In Experiment II (Bottom) Values are Means of Nine Replications in 1968 and Five Replications in 1969

TABLE IV

ANALYSES OF VARIANCE, MEAN YIELDS AND LSR VALUES OF GRAIN SORGHUM ON VANOSS SILT LOAM AT PERKINS IN 1968 AND 1969

Source of variation	df 1968	df 1969	Mean square[1] 1968	Mean square[1] 1969
Experiment I				
Blocks	3	3	11.0242**	11396.9202
N sources (N)	1	1	0.1444	32040.1214
N rates (R)	3	3	0.7188	45554.0821*
N x R	3	3	0.4695	32423.7110
Error	21	21	0.6767	13694.7303
C. V.			25.64%	4.42%
Experiment II				
Blocks[2]	-	4	-	85668.5810
N sources (N)	1	1	52900.2714	156.8024
Exposures (E)	1	1	143641.2720	36465.8004
N x E	1	1	13148.2903	25205.0021
Error	32	12	642612.5942	77447.9110
C. V.			32.57%	12.05%

Mean yields (lb/A) of Experiment I in 1969

N source	N rate (lb/A) 0	50	100	150
Urea	2729	2629	2709	2456
Ammonium nitrate	2731	2582	2631	2661

LSR Values for Experiment I in 1969

No. of pairs	2	3	4
LSR (5%)	173	181	187

[1]The analysis for Experiment I in 1968 was on lb/plot whereas in the others it was on lb/A.

[2]In 1968, Experiment II was a completely randomized design with nine "pseudo-replications" while in 1969 the experiment was a randomized complete block with five blocks.

*Significant at 5% level.
**Significant at 1% level.

effects. One suspected cause of this high variability was the uneven stand of the crop.

In 1969 (Figure 3, top right) the yield responses of grain sorghum to urea and ammonium nitrate on Vanoss silt loam was very similar to each other at all levels of N. The analysis of variance (Table IV) showed a significant difference in yields between the N rates. This significant difference was between the check and the highest (150 lb/A) of urea N. The mean yields of the other N rates from both sources of N were not significantly different from each other.

2. Experiment II. The graph at the bottom of Figure 3 shows the N exposure studies in 1968 (left) and 1969 (right). The exposure periods had no significant effect on the yield of grain sorghum in either season. It is also indicated in Figure 3 (bottom) that the yield in 1968 was higher at all levels of exposures than in 1969 for both carriers. At this juncture, it maybe mentioned that after heading (September to October) in the 1969 crop, the sorghum plants were under moisture stress for long spells on account of the inadequate irrigation water.

Muskogee. The yield of grain sorghum grown on Taloka silt loam at Muskogee for 1968 is shown at the left (top and bottom) of Figure 4 while the 1969 yield is at the right (top and bottom) of the same figure. The analyses of variance for both grain and forage sorghums are shown in Table V. The mean yields and LSR values for comparison of means are in Table VI.

1. Grain sorghum. The yield of grain sorghum (Figure 4) in both seasons was substantially the same for the two N carriers, urea and ammonium nitrate, at all N-P-K combinations (Table V). However, Table

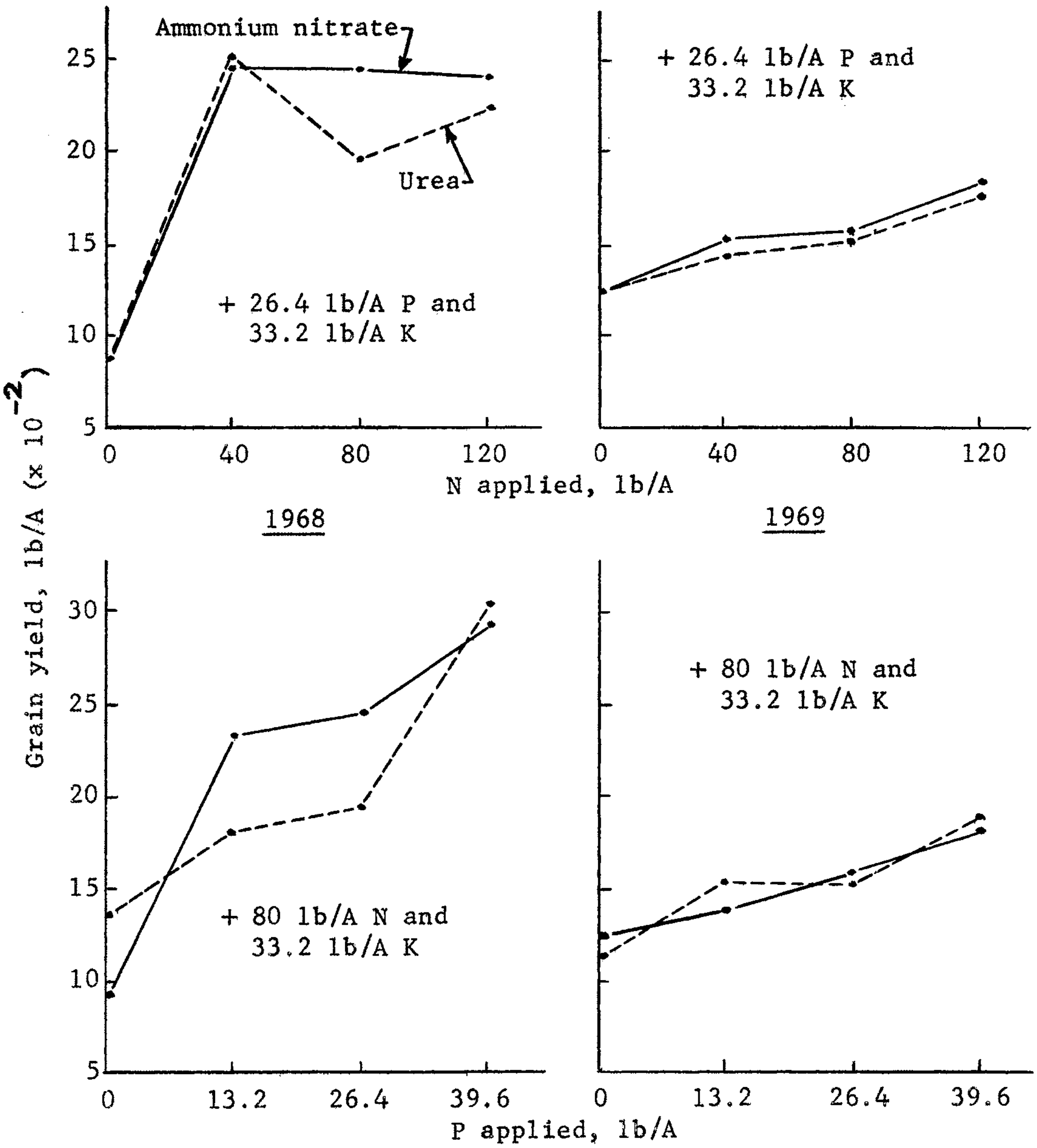


Figure 4. The Effects of Urea and Ammonium Nitrate, at Various Rates and in Combination with Varying Amounts of P and K, on the Grain Yields of OK 612 in 1968 (Left) and AKS 614 in 1969 (Right) Grown on Taloka Silt Loam at Muskogee. Values are Means of Four Replications

TABLE V

ANALYSES OF VARIANCE OF THE 1968 AND 1969 YIELDS (lb/A) OF GRAIN AND FORAGE SORGHUMS ON TALOKA SILT LOAM AT MUSKOGEE

		Mean square			
		Grain		Forage	
Source of variation	df	1968	1969	1968	1969
Blocks (B)	3	551798.9697	105302.9602*	12722385.2879**	726133.5611
N-P-K combinations (C)	10	3027969.6614**	555578.5614**	12651408.3205**	3719483.0012**
Error A (B x C)	30	216352.5947	34672.8513	1735132.4295	518139.0614
N sources (N)	1	209918.2273	100305.0101	5148793.1364	1534104.0066*
C x N	10	180387.1523	36802.0124	611648.6114	1772257.2508**
Error B	33	85754.2197	31847.2210	920613.9621	294092.0915
C. V.		13.76%	11.50%	8.54%	6.59%

TABLE VI

MEAN YIELDS (lb/A) AND LSR VALUES OF GRAIN SORGHUM AT VARIOUS N-P-K COMBINATIONS ON TALOKA SILT LOAM AT MUSKOGEE IN 1968 AND 1969

N source	lb/A											
	N	0	40	80	120	80	80	80	80	80	120	120
	P	26.4	26.4	26.4	26.4	0	13.2	39.6	26.4	26.4	39.6	39.6
	K	16.6	16.6	16.6	16.6	16.6	16.6	16.6	0	33.2	0	33.2
1968 mean yields												
Urea		591	2416	2048	2363	1418	1654	3007	2192	2482	1930	2586
Ammonium nitrate		591	2495	2468	2429	985	2245	2928	2101	2376	2206	2492
1969 mean yields												
Urea		1255	1431	1572	1762	1149	1567	1875	1198	2001	1296	1576
Ammonium nitrate		1255	1535	1592	1863	1260	1403	1840	1275	1948	1614	1814

LSR values

Number of pairs		2	3	4	5	6	7	8	9	10	11
1968:	LSR (5%)	672	707	728	745	756	765	772	780	784	790
	(1%)	906	944	972	990	1002	1017	1025	1032	1041	1053
1969:	LSR (5%)	270	284	292	299	303	307	310	313	315	316
	(1%)	363	379	390	397	402	408	412	416	418	423

V also shows that the yield was significantly affected (1% level) by the various N-P-K combinations. The 1968 yield response to N rates from both carriers was a highly significant increase from 0 to 40 lb/A N and then the yield decreased from 40 through 120 lb/A N (Figure 4, top left). The data indicate that in 1968 40 lb/A of N from urea and ammonium nitrate were adequate to effect a maximum yield response by grain sorghum.

In the 1969 crop the patterns of yield response by grain sorghum to both N and P on Taloka silt loam were different from those of 1968 (Figure 4, top and bottom). In the 1969 crop the yields at all levels of N and P were practically the same for urea and ammonium nitrate.

There was a significant yield response of grain sorghum to K applications in both years at all levels of N and P as indicated in Tables V and VI. Table VI also shows that the yields of grain sorghum in 1969 were much lower than those of 1968 at all levels of N, P and K.

2. Total nutrient uptake of grain sorghum. The yield and total mineral content (lb/A) of sorghum grain on Taloka silt loam in 1968 are shown in Table VII. The analyses of variance and correlation coefficients (r) for yield and total mineral contents are shown in Tables VIII and IX, respectively. The LSR values for total N, P and K are in Table X. No chemical analyses of the grains were made in 1969 since the treatments were the same and the conditions seemed unfavorable for plant growth.

a. Total N uptake. It is interesting to note that the first increment of P and K (26.4 and 16.6 lb/A, respectively) drastically and significantly decreased the total N in the sorghum grain when no N was applied (see the 0-0-0 and 0-26.4-16.6 plots in Table VII). This

TABLE VII

THE YIELD AND MINERAL COMPOSITION OF OK 612 GRAIN SORGHUM GROWN ON TALOKA SILT LOAM FERTILIZED WITH VARYING AMOUNTS OF UREA, AMMONIUM NITRATE, SUPERPHOSPHATE AND MURIATE OF POTASH (1968 SEASON) AT MUSKOGEE. VALUES ARE MEANS OF THREE REPLICATIONS

Rate (lb/A)			Nitrogen	Yield	Mineral composition of grain, lb/A						
N	P	K	source	(lb/A)	N	P	K	Ca	Mg	S	Na
0	0	0	Check	670	13.89	1.82	1.78	0.56	1.07	0.75	0.54
0	26.4	16.6	None	591	7.80	2.33	1.91	0.48	1.04	0.56	0.50
40	26.4	16.6	Urea	2416	38.03	6.46	6.54	3.20	4.48	2.61	2.49
			Ammonium nitrate	2495	39.77	6.36	6.55	1.16	3.56	2.40	1.13
80	26.4	16.6	Urea	2048	39.56	7.56	6.12	0.91	3.54	2.08	0.88
			Ammonium nitrate	2468	47.07	8.60	7.36	1.20	4.03	2.84	1.07
120	26.4	16.6	Urea	2363	46.73	6.61	6.15	1.16	3.38	2.46	0.98
			Ammonium nitrate	2429	46.82	6.71	6.17	3.65	4.29	3.29	2.17
80	0	16.6	Urea	1418	28.60	3.68	3.46	0.82	1.88	1.38	0.65
			Ammonium nitrate	985	21.22	2.97	2.73	0.45	1.24	1.10	0.43
80	13.2	16.6	Urea	1654	33.34	5.37	4.91	0.79	2.66	1.86	0.69
			Ammonium nitrate	2245	44.01	6.30	6.28	1.39	3.29	2.37	1.00
80	39.6	16.6	Urea	3007	54.00	9.89	8.51	1.57	4.83	3.20	1.31
			Ammonium nitrate	2928	51.20	9.57	8.13	1.69	4.70	2.94	1.34

Continued next page

TABLE VII Continued:

Rate (lb/A)			Nitrogen	Yield	Mineral composition of grain, lb/A						
N	P	K	source	(lb/A)	N	P	K	Ca	Mg	S	Na
80	26.4	0	Urea	2192	44.46	7.75	6.08	0.96	3.70	2.43	0.91
			Ammonium nitrate	2101	42.63	7.14	5.93	1.05	3.48	2.16	0.89
80	26.4	33.2	Urea	2482	45.86	8.31	8.27	1.62	4.48	3.18	1.10
			Ammonium nitrate	2376	43.47	6.42	6.77	0.96	3.45	2.34	1.04
120	39.6	0	Urea	1930	41.95	6.52	5.31	0.94	3.13	2.04	3.71
			Ammonium nitrate	2206	46.52	8.51	6.89	1.21	4.18	2.49	0.93
120	39.6	33.2	Urea	2586	50.12	8.39	7.45	1.18	4.01	2.71	1.17
			Ammonium nitrate	2492	47.01	8.26	7.55	1.05	4.46	2.90	1.07

TABLE VIII

SUMMARY OF ANALYSES OF VARIANCE FOR TOTAL MINERAL CONTENTS OF GRAIN AND FORAGE SORGHUMS ON TALOKA SILT LOAM IN 1968 AT MUSKOGEE

Source of variation	df	Mean square						
		N	P	K	Ca	Mg	S	Na
Grain sorghum								
Blocks (B)	2	410.7953	6.6928	7.6738	1.2107	3.9526	1.1082*	4.3294
N-P-K combinations (C)	10	9633.6427**	27.9911**	21.6838**	2.0848	7.7941**	3.3789**	1.7973
Error A (B x C)	20	1427.4551	4.1822	2.9222	1.1157	1.3349	0.2481	1.4672
N sources (N)	1	6.7840	0.0123	0.3304	0.0576	0.0088	0.1088	1.0819
C x N	10	405.9801	1.5777	1.2977	1.7102	0.7251	0.4001	1.5706
Error B	22	736.5939	1.7796	1.0446	1.1672	0.5048	0.2031	1.5471
Forage sorghum								
Blocks (B)	2	3696.2020**	121.6544**	1409.1522**	111.6323**	119.7043**	85.5448**	0.9001
N-P-K combinations (C)	10	2024.6942**	4.1209	552.2090**	88.1840**	130.9449*	3.4559*	1.3138
Error A (B x C)	20	355.2447	2.5071	50.1461	18.3153	13.2453	1.1824	0.5631
N sources (N)	1	71.7814	0.0128	18.9230	20.1193	2.8107	0.4854	0.1040
C x N	10	102.8494	0.5613	41.9215	10.8928	14.7624	0.6112	0.4136
Error B	22	104.2508	0.7180	39.5063	6.7948	8.2794	0.9852	0.3737

*Significant at 5% level.
**Significant at 1% level.

TABLE IX

CORRELATION COEFFICIENTS (r'S) OF YIELDS AND TOTAL MINERAL CONTENTS OF GRAIN AND FORAGE SORGHUMS ON TALOKA SILT LOAM AT MUSKOGEE IN 1968

Variables	r-values						
	N	P	K	Ca	Mg	S	Na
				Grain sorghum			
Yield	0.96**	0.89**	0.94**	0.36**	0.88**	0.91**	0.27*
N	x	0.90**	0.91**	0.26*	0.83**	0.89**	0.26*
P	x	x	0.95**	0.21	0.90**	0.88**	0.19
K	x	x	x	0.26*	0.93**	0.94**	0.22
Ca	x	x	x	x	0.48**	0.42**	0.43**
Mg	x	x	x	x	x	0.92**	0.36**
S	x	x	x	x	x	x	0.28*
				Forage sorghum			
Yield	0.60**	0.62**	0.68**	0.61**	0.60**	0.49**	0.50**
N	x	0.63**	0.43**	0.66**	0.80**	0.71**	0.37**
P	x	x	0.63**	0.56**	0.58**	0.71**	0.26*
K	x	x	x	0.26*	0.25*	0.56**	0.45**
Ca	x	x	x	x	0.87**	0.55**	0.35**
Mg	x	x	x	x	x	0.63**	0.24
S	x	x	x	x	x	x	0.38**

*Significant at 5% level.
**Significant at 1% level.

TABLE X

LSR VALUES FOR TOTAL N, P AND K CONTENTS OF GRAIN AND FORAGE SORGHUMS ON TALOKA SILT LOAM IN 1968 AT MUSKOGEE. THE MEAN CONTENTS OF THESE MINERALS ARE SHOWN IN TABLES VII FOR GRAIN AND XII FOR FORAGE SORGHUM

Mineral	α level	Number of pairs									
		2	3	4	5	6	7	8	9	10	11
						Grain sorghum					
N	5%	64.40	67.51	68.60	71.00	72.06	72.78	73.49	74.00	74.45	74.78
	1%	87.81	91.47	94.18	95.86	97.31	98.49	99.50	100.02	101.04	102.00
P	5%	3.48	3.65	3.76	3.84	3.90	3.94	3.97	4.00	4.02	4.05
	1%	4.75	4.95	5.09	5.18	5.26	5.32	5.39	5.42	5.45	5.51
K	5%	2.92	3.06	3.16	3.22	3.27	3.31	3.34	3.36	3.38	3.40
	1%	3.98	4.15	4.27	4.35	4.42	4.47	4.52	4.54	4.57	4.61
						Forage sorghum					
N	5%	32.18	33.72	34.79	35.46	36.00	36.39	36.72	36.99	37.19	37.43
	1%	43.88	45.69	47.09	47.87	48.60	49.18	49.60	50.00	50.32	50.89
P	5%	2.71	2.84	2.93	2.99	3.04	3.07	3.10	3.12	3.14	3.46
	1%	3.70	3.86	3.97	4.04	4.11	4.15	4.19	4.22	4.25	4.28
K	5%	12.15	12.74	13.13	13.40	13.60	13.75	13.89	13.97	14.04	14.16
	1%	16.58	17.27	17.78	18.10	18.39	18.60	18.76	18.92	19.02	19.21

phenomenon is commonly observed on soils very low in available N.

As shown in Tables VIII and X the N content in the grain varied significantly (1% level) between the N-P-K combinations. In each of the N-P-K combination, however, the total N of the grain from the urea and ammonium nitrate plots were not significantly different from each other (Table VIII). The lowest N content was 7.80 lb/A in the 0-26.4-16.6 series and the highest was 54.00 lb/A at the 80-39.6-16.6 plots.

b. Total P uptake. The total P in the sorghum grain varied significantly (1% level) between the N-P-K combinations (Tables VIII and X). The lowest P uptake was 1.82 lb/A from the check plots (0-0-0) and the highest was 9.89 lb/A from 80-39.6-16.6 series. At all combinations of N-P-K the trend in total P in the grain followed a pattern very close to that of N uptake.

c. Total K uptake. K in the sorghum grain varied significantly (1% level) between the N-P-K combinations (Tables VIII and X). The lowest was 1.28 lb/A in the 0-0-0 plots and the highest was 8.51 lb/A in the 80-39.6-16.6 series. The K uptakes from the urea and ammonium nitrate plots were not significantly different from each other at any N-P-K combination.

The effects of N, P and K applications to grain sorghum on the per cent of total mineral contents in the grain are shown in Table XI along with the other minerals analyzed. Although per cent N, P and K showed definite patterns of response to N, P and K applications, the per cent Ca, Mg, S and Na appear to be a function of yield.

3. Forage sorghum. The dry matter yields of forage sorghum on Taloka silt loam receiving varying amounts of N, P and K are shown in Figure 5 for 1968 (left, top and bottom) and 1969 (right, top and bottom),

TABLE XI

THE PER CENT TOTAL MINERAL CONTENTS OF GRAIN SORGHUM ON TALOKA SILT LOAM FERTILIZED WITH VARYING AMOUNTS OF N, P AND K IN 1968 AT MUSKOGEE. VALUES ARE MEANS OF THREE REPLICATIONS

N-P-K combination	Nitrogen source	Total mineral content in the grain (% of yield)						
		N	P	K	Ca	Mg	S	Na
0 -26.4-16.6	Urea	1.33	0.40	0.32	0.097	0.18	0.099	0.099
	Ammonium nitrate	1.33	0.40	0.32	0.097	0.18	0.099	0.099
40-26.4-16.6	Urea	1.59	0.27	0.27	0.127	0.18	0.106	0.100
	Ammonium nitrate	1.59	0.26	0.26	0.048	0.14	0.098	0.046
80-26.4-16.6	Urea	1.95	0.37	0.29	0.044	0.17	0.101	0.043
	Ammonium nitrate	1.91	0.35	0.29	0.048	0.16	0.116	0.043
120-26.4-16.6	Urea	1.97	0.28	0.26	0.049	0.14	0.104	0.042
	Ammonium nitrate	1.93	0.27	0.25	0.154	0.18	0.136	0.097
80- 0 -16.6	Urea	2.01	0.26	0.25	0.056	0.13	0.097	0.045
	Ammonium nitrate	2.16	0.31	0.29	0.044	0.13	0.114	0.046
80-13.2-16.6	Urea	2.01	0.32	0.29	0.048	0.16	0.109	0.040
	Ammonium nitrate	1.98	0.28	0.28	0.060	0.13	0.105	0.045
80-39.6-16.6	Urea	1.58	0.33	0.28	0.052	0.18	0.106	0.044
	Ammonium nitrate	1.74	0.33	0.28	0.059	0.16	0.099	0.046

Continued next page

TABLE XI Continued:

N-P-K combination	Nitrogen source	Total mineral content in the grain (% of yield)						
		N	P	K	Ca	Mg	S	Na
80-26.4- 0	Urea	3.01	0.35	0.27	0.042	0.13	0.113	0.040
	Ammonium nitrate	2.03	0.34	0.21	0.054	0.16	0.103	0.042
80-26.4-33.2	Urea	1.84	0.33	0.33	0.068	0.18	0.125	0.045
	Ammonium nitrate	1.84	0.27	0.29	0.040	0.14	0.101	0.044
120-39.6- 0	Urea	2.16	0.34	0.28	0.047	0.16	0.109	0.167
	Ammonium nitrate	2.12	0.39	0.32	0.055	0.19	0.114	0.042
120-39.6-33.2	Urea	1.95	0.33	0.29	0.046	0.16	0.104	0.045
	Ammonium nitrate	1.89	0.33	0.30	0.049	0.18	0.115	0.043

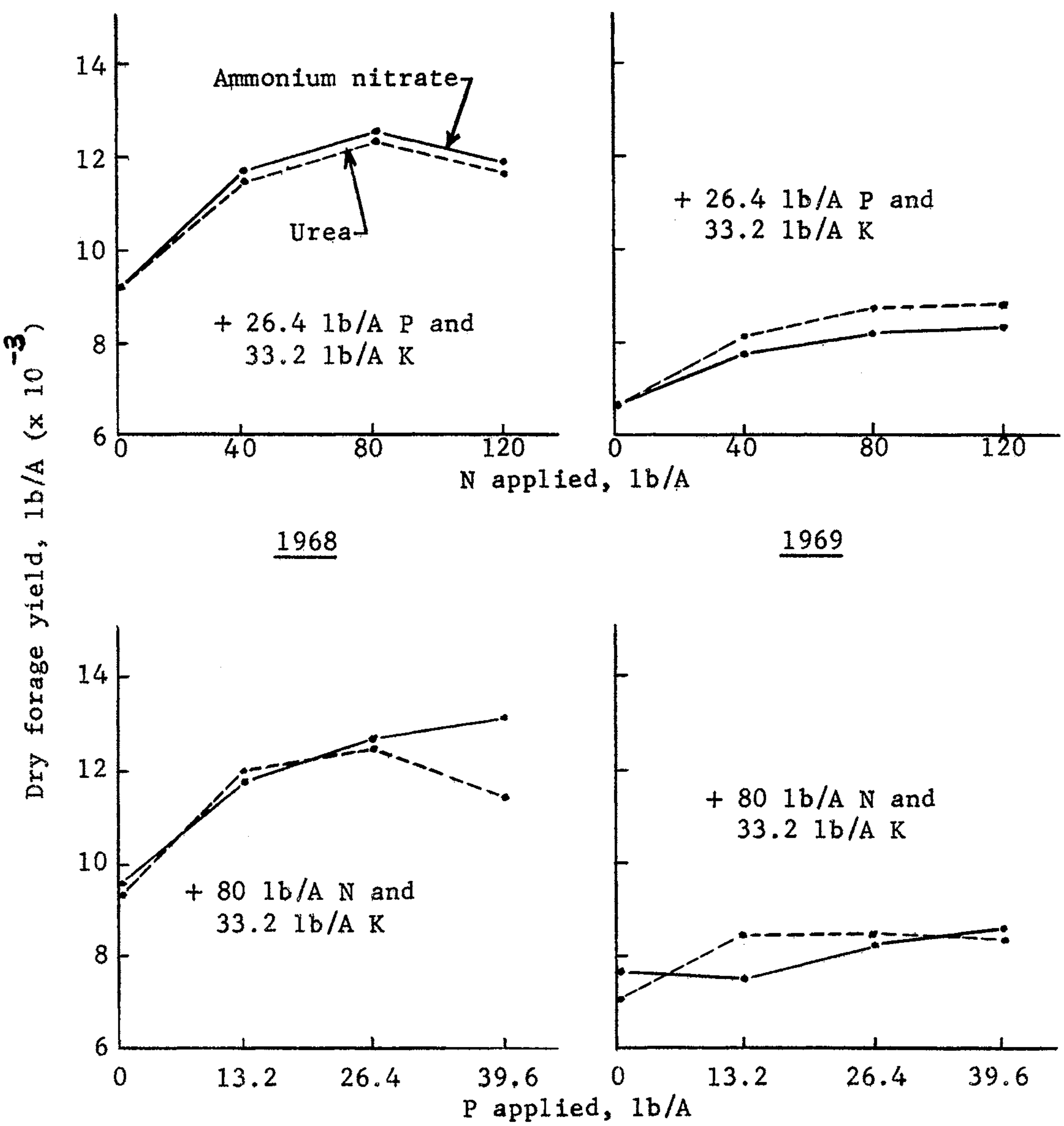


Figure 5. The Effects of Urea and Ammonium Nitrate, at Various Rates and in Combination with Varying Amounts of P and K, on the Dry Forage Yield of Sugar Drip Sorghum Grown on Taloka Silt Loam at Muskogee in 1968 (Left) and 1969 (Right). Values are Means of Four Replications

and in Table XIII for both seasons. There were significant differences in yields between urea and ammonium nitrate during both seasons (Table V). In 1968 this substantial difference due to N sources was at the 80-26.4-0 combination while in 1969 the difference was at the N-P-K combination of 120-39.6-33.2 (Tables X and XII).

4. Nutrient uptakes by forage sorghum. The yield and mineral composition of Sugar Drip forage sorghum grown on Taloka silt loam in 1968 are reported in Table XII. The analyses of variance and correlations of yield and the minerals are in Tables VIII and IX, respectively.

a. Total N uptake. As in the case of grain sorghum, N uptake of forage sorghum decreased at the first increment of P and K when no N was applied (Table XII). The N content in the forage was substantially the same for both urea and ammonium nitrate plots (Tables VIII and X), but varied significantly (1% level) between N-P-K combinations. This wide variability ranged from 31.30 lb/A from the 0-26.4-16.6 plots to 98.63 lb/A from the 120-39.6-0 plots. For both N carriers, the highest N content in the forage was from the 120-39.6-33.2 plots.

b. Total P uptake. There were no significant differences in total P of the sorghum forage between the different N-P-K combinations and between the two sources of N as indicated in Tables VIII and X. The maximum P absorbed by the forage sorghum (6.28 lb/A) was found at the highest rates of N, P and K. The minimum total P content (2.55 lb/A) was at the 80-0-16.6 plots.

c. Total K uptake. The K uptake by forage sorghum varied significantly (1% level) between N-P-K combinations but not between N sources (Table VIII). The lowest K in the forage (21.70 lb/A) was

TABLE XII

THE YIELD AND MINERAL COMPOSITION OF FORAGE SORGHUM (VAR. SUGAR DRIP) GROWN ON TALOKA SILT LOAM IN 1968 AT MUSKOGEE WITH VARYING AMOUNTS OF UREA, AMMONIUM NITRATE, SUPERPHOSPHATE AND MURIATE OF POTASH. VALUES ARE MEANS OF THREE REPLICATIONS

lb/A applied			Nitrogen source	Yield	Total mineral content of dry forage, lb/A						
N	P	K		(lb/A)	N	P	K	Ca	Mg	S	Na
0	0	0	Check	8077	34.97	3.07	26.66	18.06	15.51	4.15	2.11
0	26.4	16.6	None	9722	31.20	4.36	37.90	19.12	14.31	4.38	2.67
40	26.4	16.6	Urea	11650	58.43	4.57	46.00	25.90	26.06	5.63	2.47
			Ammonium nitrate	11639	54.08	3.78	37.83	23.52	20.61	5.08	2.50
80	26.4	16.6	Urea	12077	83.63	5.73	41.08	25.77	27.58	6.79	3.00
			Ammonium nitrate	12465	77.33	5.09	39.95	27.81	28.12	6.72	3.58
120	26.4	16.6	Urea	11257	84.25	4.76	33.43	21.77	23.60	5.79	2.68
			Ammonium nitrate	11651	96.12	5.44	43.21	25.49	27.33	6.65	2.82
80	0	16.6	Urea	9515	68.57	2.55	32.97	18.40	16.85	4.89	2.12
			Ammonium nitrate	9808	69.49	2.82	37.01	16.98	15.99	5.37	2.79
80	13.2	16.6	Urea	11819	89.23	4.17	42.48	26.31	25.59	6.01	3.48
			Ammonium nitrate	11589	80.43	3.77	41.83	26.38	23.92	5.44	3.13
80	39.6	16.6	Urea	11983	81.03	4.97	39.75	29.32	27.62	6.15	3.28
			Ammonium nitrate	12263	77.51	4.66	36.03	29.00	26.43	5.65	3.13

Continued next page

TABLE XII Continued:

lb/A applied			Nitrogen source	Yield	Total mineral content of dry forage, lb/A						
N	P	K		(lb/A)	N	P	K	Ca	Mg	S	Na
80	26.4	0	Urea	9109	74.66	4.31	21.70	24.12	26.34	5.43	2.68
			Ammonium nitrate	10267	83.66	5.07	23.45	30.94	28.74	5.62	2.68
80	26.4	33.2	Urea	11573	80.87	4.46	47.29	23.41	23.42	5.31	3.26
			Ammonium nitrate	11843	83.82	4.67	54.37	23.44	24.13	5.90	3.80
120	39.6	0	Urea	9609	80.00	4.33	21.08	27.46	25.32	5.70	3.32
			Ammonium nitrate	10186	98.63	5.09	27.00	31.18	32.03	7.17	2.51
120	39.6	33.2	Urea	12145	94.52	6.28	56.30	27.74	26.51	7.02	3.96
			Ammonium nitrate	12216	97.07	5.44	53.20	27.59	26.14	7.02	3.40

TABLE XIII

MEAN YIELDS (lb/A) AND LSR VALUES OF FORAGE SORGHUM AT VARIOUS N-P-K COMBINATIONS ON TALOKA SILT LOAM AT MUSKOGEE IN 1968 AND 1969

Nitrogen source / lb/A											
N	0	40	80	120	80	80	80	80	80	120	120
P	26.4	26.4	26.4	26.4	0	13.2	39.6	26.4	26.4	39.6	39.6
K	16.6	16.6	16.6	16.6	16.6	16.6	16.6	0	33.2	0	33.2
1968 mean yields											
Urea	9722	11650	12077	11257	9515	11819	11983	9109	11573	9609	12145
Ammonium nitrate	9722	11639	12465	11651	9808	11589	12263	10267	11843	10186	12216
1969 mean yields											
Urea	6711	8298	8687	8852	7140	8681	8296	8930	8156	3139	9968
Ammonium nitrate	6711	7865	8188	8364	7770	7927	8874	8095	8262	8114	8783

LSR values

Number of pairs		2	3	4	5	6	7	8	9	10	11
1968:	LSR (5%)	1002	1054	1089	1111	1128	1142	1156	1165	1172	1178
	(1%)	1350	1411	1450	1479	1500	1520	1534	1550	1559	1568
1969:	LSR (5%)	1040	1095	1128	1152	1150	1184	1196	1207	1213	1218
	(1%)	1400	1463	1502	1530	1553	1575	1590	1602	1613	1618

from the 80-26.4-0 plots. This value was significantly lower than the K content of forage in the check plots. The highest K uptake was 56.30 lb/A from the highest N-P-K rates. The significant differences in total N, P and K contents of the forage sorghum can be determined through Tables X and XII which show the least significant range values and mean N, P and K contents, respectively.

The effects of N, P and K applications to forage sorghum on the per cent total mineral contents in the grain are reported in Table XIV. Tables IX and XIV indicate that the per cent of Ca, Mg, S and Na in the forage sorghum are a function of yield. On the other hand, the per cent N, P and K show definite patterns of responses to applications of N, P and K.

Bermudagrass

The data from the bermudagrass experiment are reported in Tables XV to XVII and Figure 6. Only two cuttings or clippings were made in this study.

Yield. In the first clipping there was a highly significant increase in yield from 0 to 200 lb/A of N (Table XVI and Figure 6, left). The yield did not increase substantially from 200 to 400 lb/A of N. No significant difference in yield existed between urea and ammonium nitrate treatments at all levels of N. The yield ranged from 2686 lb/A (dry forage) in the check plots to 6077 lb/A in the plots with 400 lb/A of N.

The yield from the second clipping was also significantly affected by N rates but not by N sources. However, compared to the first clipping, the second clipping yielded only about one-fifth as much dry

TABLE XIV

THE PER CENT TOTAL MINERAL CONTENTS OF FORAGE SORGHUM ON TALOKA SILT LOAM FERTILIZED WITH VARYING AMOUNTS OF N, P AND K IN 1968 AT MUSKOGEE. VALUES ARE MEANS OF THREE REPLICATIONS

N-P-K combination	Nitrogen source	Total mineral content in the forage (% of yield)						
		N	P	K	Ca	Mg	S	Na
0 -26.4-16.6	Urea	0.32	0.044	0.39	0.23	0.14	0.044	0.027
	Ammonium nitrate	0.32	0.044	0.39	0.23	0.14	0.044	0.027
40-26.4-16.6	Urea	0.50	0.038	0.39	0.22	0.22	0.048	0.021
	Ammonium nitrate	0.47	0.033	0.34	0.20	0.18	0.044	0.023
80-26.4-16.6	Urea	0.69	0.047	0.34	0.21	0.22	0.056	0.024
	Ammonium nitrate	0.62	0.041	0.32	0.33	0.23	0.054	0.029
120-26.4-16.6	Urea	0.74	0.041	0.30	0.19	0.31	0.051	0.024
	Ammonium nitrate	0.81	0.043	0.36	0.22	0.23	0.056	0.024
80- 0 -16.6	Urea	0.72	0.026	0.34	0.19	0.18	0.051	0.022
	Ammonium nitrate	0.71	0.025	0.38	0.17	0.16	0.055	0.028
80-13.2-16.6	Urea	0.75	0.035	0.36	0.21	0.22	0.050	0.030
	Ammonium nitrate	0.69	0.032	0.36	0.23	0.21	0.047	0.027
80-39.6-16.6	Urea	0.67	0.041	0.33	0.25	0.23	0.052	0.028
	Ammonium nitrate	0.63	0.037	0.30	0.24	0.22	0.047	0.026

Continued next page

TABLE XIV Continued:

N-P-K combination	Nitrogen source	Total mineral content in the forage (% of yield)						
		N	P	K	Ca	Mg	S	Na
80-26.4- 0	Urea	0.83	0.047	0.24	0.26	0.29	0.061	0.021
	Ammonium nitrate	0.81	0.049	0.23	0.30	0.28	0.045	0.028
80-26.4-33.2	Urea	0.69	0.039	0.41	0.30	0.20	0.045	0.028
	Ammonium nitrate	0.69	0.036	0.46	0.20	0.21	0.047	0.032
120-39.6- 0	Urea	0.83	0.043	0.22	0.29	0.26	0.059	0.036
	Ammonium nitrate	0.96	0.050	0.27	0.30	0.32	0.070	0.025
120-39.6-33.2	Urea	0.77	0.050	0.47	0.23	0.22	0.058	0.033
	Ammonium nitrate	0.79	0.043	0.43	0.22	0.21	0.057	0.027

TABLE XV

THE DRY FORAGE YIELD AND TOTAL MINERAL CONTENTS OF BERMUDAGRASS GROWN ON PORT LOAM AT STILLWATER (FIRST CLIPPING) FERTILIZED WITH VARYING AMOUNTS OF UREA AND AMMONIUM NITRATE. VALUES ARE MEANS OF FOUR REPLICATIONS

N rate (lb/A)	N source	Yield (lb/A)	Total mineral content in forage (lb/A)						
			N	P	K	Ca	Mg	S	Na
0	None	2686	29.3	6.9	38.6	4.5	3.7	8.0	1.1
100	Urea	5040	90.0	14.1	90.1	5.9	8.7	17.0	3.1
	Ammonium nitrate	4374	83.4	12.5	76.2	6.4	7.9	14.9	1.9
200	Urea	5711	136.8	15.7	114.8	8.2	10.6	18.4	5.2
	Ammonium nitrate	5596	127.8	14.8	103.1	8.4	10.6	19.2	4.7
400	Urea	6077	160.7	16.3	107.8	8.6	10.9	18.9	7.0
	Ammonium nitrate	6020	160.0	15.4	106.2	12.7	11.8	19.4	7.7

TABLE XVI

THE ANALYSIS OF VARIANCE, MEAN YIELDS AND LSR VALUES FOR BERMUDAGRASS ON PORT LOAM AT STILLWATER FERTILIZED WITH VARYING RATES OF UREA AND AMMONIUM NITRATE

Source of variation	df	Mean square 1st clipping	Mean square 2nd clipping
Blocks	3	570566.7917**	108783.1560
N sources (N)	1	350703.1250	338458.7812
N rates (R)	3	18028965.4583**	12062464.3631**
N x R	3	189341.7917	54358.1144
Error	21	109815.6964	46927.6565
C. V.		23.26%	10.01%

Mean yields (lb/A)

N source	N rate (lb/A) 0	100	200	400
1st clipping				
Urea	2686	5040	5711	6077
Ammonium nitrate	2686	4374	5596	6020
2nd clipping				
Urea	968	1760	2295	3991
Ammonium nitrate	968	1416	2150	3660

LSR values

	Number of pairs					
	1st clipping			2nd clipping		
α level	2	3	4	2	3	4
5%	409	512	529	319	334	344
1%	666	694	715	434	452	466

**Significant at 1% level.

TABLE XVII

SUMMARY OF ANALYSES OF VARIANCE AND CORRELATION COEFFICIENTS (r'S) OF YIELD AND MINERAL CONTENTS OF BERMUDAGRASS GROWN ON PORT LOAM AT STILLWATER (FIRST CLIPPING)

		Mineral contents in the forage						
		N	P	K	Ca	Mg	S	Na
		Analyses of variance						
Source of variation	df	Mean square						
Blocks	3	233.5709	6.0580**	96.2335	2.0618	2.6769**	4.0315*	1.6824
N sources (N)	1	133.4160	6.2481	369.1725*	11.6765**	0.0058	0.2946	0.4512
N rates (R)	3	26222.2704**	134.2539**	8562.2521**	56.2247**	93.7241**	217.8806**	60.5931**
N x R	3	38.3886	0.9194	99.1160	7.4653	0.7951	3.3720	1.2812
Error	21	223.0000	0.9960	63.7000	1.2460	0.5260	1.2530	0.6760
Variables		Correlation coefficients (r's)						
Yield		0.96**	0.97**	0.98**	0.79**	0.97**	0.96**	0.87**
Nitrogen content		x	0.92**	0.93**	0.85**	0.96**	0.91**	0.93**
Phosphorus content		x	x	0.96**	0.69**	0.94**	0.94**	0.82**
Potassium content		x	x	x	0.75**	0.96**	0.95**	0.83**
Calcium content		x	x	x	x	0.84**	0.73**	0.84**
Magnesium content		x	x	x	x	x	0.97**	0.89**
Sulfur content		x	x	x	x	x	x	0.82**

*Significant at 5% level.
**Significant at 1% level.

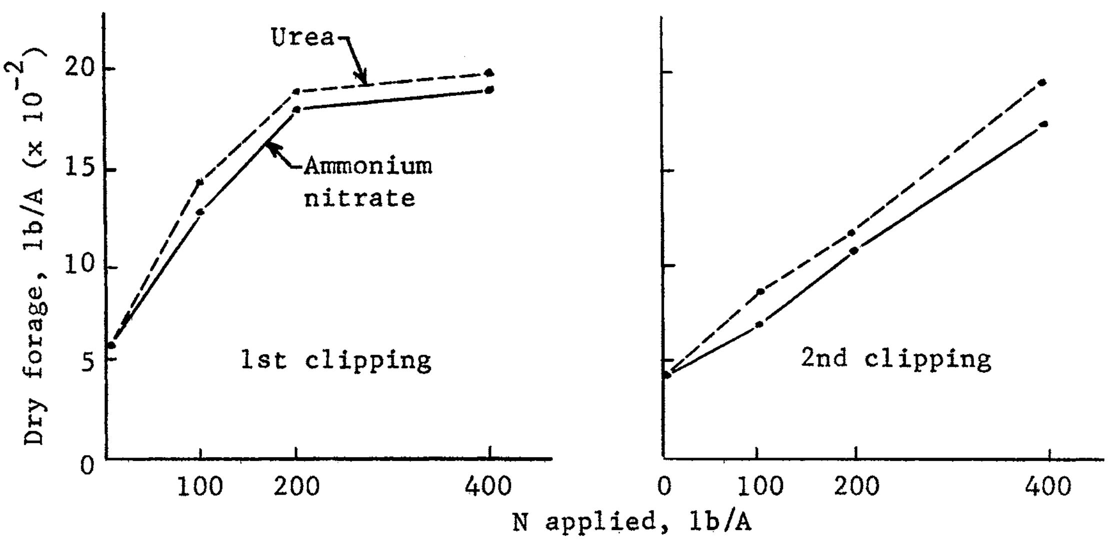


Figure 6. The Effects of Urea and Ammonium Nitrate at Varying Rates on the Yields of Bermudagrass Grown on Port Loam at Stillwater

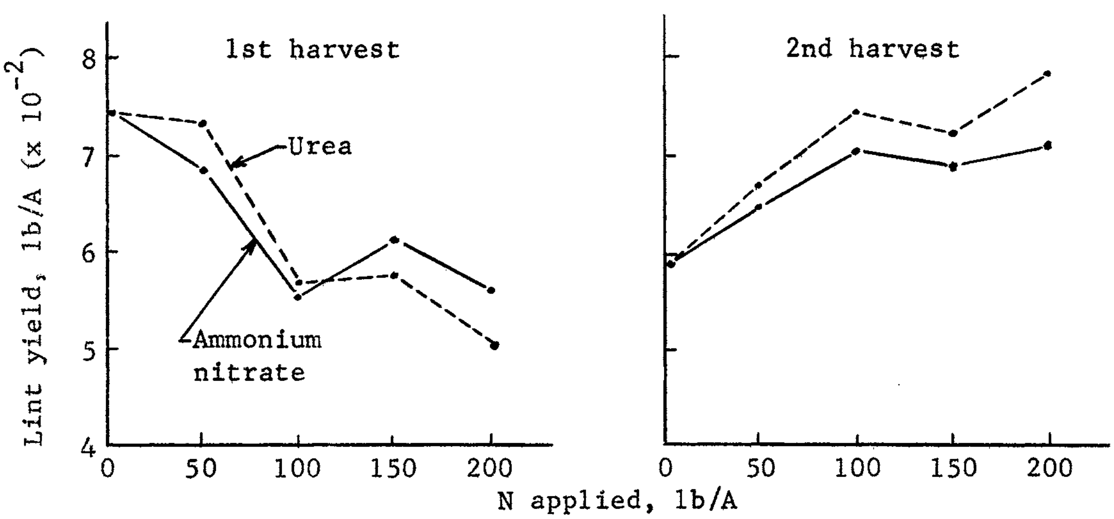


Figure 7. The Effects of Varying Rates of Urea and Ammonium Nitrate on the Lint Yields of Cotton Grown on Hollister Silty Clay Loam at Altus

matter. It is apparent that all N rates had a residual effect on the second clipping and this effect was linearly related to the application rates. Whereas in the first clipping the yield tended to remain the same after 200 lb/A N, in the second clipping the yield significantly and linearly increased from 0 to 400 lb/A N, regardless of N source.

Mineral uptakes. The total mineral contents of the first cutting of bermudagrass are reported in Table XV. The yield and mineral contents in the forage were all significantly correlated (1% level) with one another as indicated in Table XVII.

1. Total N content. The trend in N uptake by bermudagrass was a typical response curve from 0 to 400 lb/A N for both N sources as indicated in Table XV. There was no significant difference in N content from the urea and ammonium nitrate plots at all levels of N. There was a significant increase in N content from the lowest to the highest rate of N despite the fact that the yield almost stopped increasing after 200 lb/A N (1st clipping, Figure 6 left). The N uptake data suggest that even though the maximum forage yield was almost attained at 200 lb/A of N, the maximum N content (hence also the protein content) continued to increase up to 400 lb/A of N.

2. Total P content. The P uptake in the forage was significantly affected by N rates but not by N sources. The significant response in P content was between the check and the plots receiving 100 lb/A N. The P contents from 100 to 400 lb/A of P were not significantly different from each other.

3. Total K content. The trend in K uptake was similar to that of N from 0 to 400 lb/A. The significant difference in K uptake due to N rates was from 0 through 200 lb/A N. The total K content in the forage

was substantially the same for both N carriers. The LSR values for the N, P and K contents in the dry forage of bermudagrass for the first clipping are shown in Table XVIII.

TABLE XVIII

LSR VALUES OF TOTAL N, P AND K CONTENTS IN BERMUDAGRASS ON PORT LOAM AT STILLWATER FERTILIZED WITH VARYING AMOUNTS OF UREA AND AMMONIUM NITRATE (FIRST CLIPPING)

Mineral content	α level	Number of pairs 2	3	4
N	5%	22.41	23.50	24.24
	1%	30.59	31.82	32.80
P	5%	2.86	3.00	3.09
	1%	3.90	4.06	4.18
K	5%	8.56	8.98	9.26
	1%	11.66	12.15	12.50

As indicated in Table XIX the per cent total N, P and K contents in bermudagrass for the first cutting had definite response patterns to N applications. The per cent total Ca, Mg, S and Na appear to be a function of the yield.

Cotton Experiment

The experimental data from the cotton field trials are shown in Figure 7 (bottom of page 63) and Tables XX and XXI.

Lint yield. No significant difference in lint yield was obtained between urea and ammonium nitrate treatments during the first and second harvests. However, significant differences in lint yields were obtained from the varying amounts of N applied during the two harvests.

TABLE XIX

THE MEAN PER CENT TOTAL MINERAL CONTENTS IN BERMUDAGRASS GROWN ON PORT LOAM AT STILLWATER AND FERTILIZED WITH VARYING AMOUNTS OF UREA AND AMMONIUM NITRATE (FIRST CLIPPING)

N rate		Mineral contents						
(lb/A)	Nitrogen source	N	P	K	Ca	Mg	S	Na
Check	Urea	1.09	0.26	1.43	0.18	0.14	0.30	0.043
	Ammonium nitrate	1.09	0.26	1.43	0.18	0.14	0.30	0.043
100	Urea	1.79	0.28	1.79	0.12	0.17	0.34	0.062
	Ammonium nitrate	1.90	0.28	1.74	0.15	0.18	0.34	0.045
200	Urea	2.38	0.27	2.01	0.14	0.18	0.32	0.091
	Ammonium nitrate	2.29	0.26	1.84	0.15	0.19	0.34	0.085
400	Urea	2.64	0.27	1.80	0.14	0.18	0.31	0.115
	Ammonium nitrate	2.66	0.25	1.79	0.21	0.20	0.32	0.129

TABLE XX

THE TOTAL LINT YIELD FROM TWO HARVESTS OF COTTON GROWN ON AN IRRIGATED HOLLISTER SILTY CLAY LOAM AT ALTUS WITH VARYING AMOUNTS OF N FROM UREA AND AMMONIUM NITRATE. VALUES ARE MEANS OF THREE REPLICATIONS

Nitrogen source					
Urea	847	877	740	743	705
Ammonium nitrate	847	817	708	769	727

TABLE XXI

ANALYSES OF VARIANCE OF LINT AND SEED YIELDS OF COTTON GROWN ON IRRIGATED HOLLISTER SILTY CLAY LOAM AT ALTUS WITH VARYING AMOUNTS OF UREA AND AMMONIUM NITRATE VALUES ARE MEANS OF THREE REPLICATIONS

Source of variation	df	Mean square 1st clipping	Mean square 2nd clipping
		Lint yield	
Blocks	2	990.0352	997.4330
N sources (N)	1	456.3004	2133.6331
N rates (R)	4	53116.8852**	5735.8003*
N x R	4	2805.5501	264.3004
Error	18	1993.7360	748.5811
C. V.		7.23%	18.75%
		Seed yield	
Blocks	2	696.9300	1403.0331
N sources (N)	1	3921.6421	6307.5001
N rates (R)	4	54189.7402*	29823.4160**
N x R	4	10352.9210	1140.5833
Error	18	5896.8201	1203.4770
C. V.		6.87%	13.61%

*Significant at 5% level.
**Significant at 1% level.

The lint yield response to N applications in the first harvest was more or less linearly decreasing from 0 to 200 lb/A of N as shown in Figure 7, page 63. On the other hand, the lint yield response to N during the second harvest was more or less linearly increasing from 0 to 200 lb/A of N. These two opposing lint yield responses (first and second harvests) suggest that as the N increased, maturity period of the cotton bolls was lengthened so that more green bolls were left after the first harvest. Therefore, during the second harvest more bolls were gathered resulting in an increasing lint yield with increasing N rates. Summing up the two harvests (Table XX), it can be seen that N tended to depress lint yield with increasing rate of application. The significant differences in lint yields due to N applications during the first and second harvests can be determined through Table XXII.

Quality of lint. Although the lint yield had been adversely affected by N fertilization in this cropping season, the quality of lint is discussed here. The reason for this discussion is simply to have an idea of what may happen to the lint quality in this situation, and not to provide basic facts about the effects of N on lint quality under "normal" growing conditions.

The fiber length (Figure 8, top) did not show a definite trend with respect to urea and ammonium nitrate applications. Fiber coarseness, however, showed a definite decreasing trend with increasing N from both sources (Figure 8, bottom). Probably, as N increased and maturity was delayed, the fiber did not fully develop.

The 1/8-inch gauge fiber strength did not show a definite trend with increasing N (Figure 9, bottom). The 0-inch gauge fiber strength indicated an apparent trend due to increasing N (Figure 9, top). This

TABLE XXII

THE MEAN YIELDS AND LSR VALUES OF LINT AND SEEDS OF COTTON ON IRRIGATED HOLLISTER SILTY CLAY LOAM AT ALTUS WITH VARYING RATES OF UREA AND AMMONIUM NITRATE

	1st harvest					2nd harvest				
	N rate (lb/A)					N rate (lb/A)				
Nitrogen source	0	50	100	150	200	0	50	100	150	200
				Mean lint yields (lb/A)						
Urea	748	691	557	621	567	99	126	151	145	160
Ammonium nitrate	748	742	565	579	510	99	135	175	164	195
				Mean seed yields (lb/A)						
Urea	1181	1189	1217	1018	1016	155	193	293	287	276
Ammonium nitrate	1181	1223	1077	1083	942	155	220	313	307	350

LSR values

	Number of pairs (1st harvest)				Number of pairs (2nd harvest)			
α level	2	3	4	5	2	3	4	5
				For lint yield				
5%	108	114	117	119	67	70	72	73
1%	149	155	159	163	91	95	98	100
				For seed yield				
5%	186	195	201	205	84	88	91	93
1%	256	266	473	478	115	120	124	126

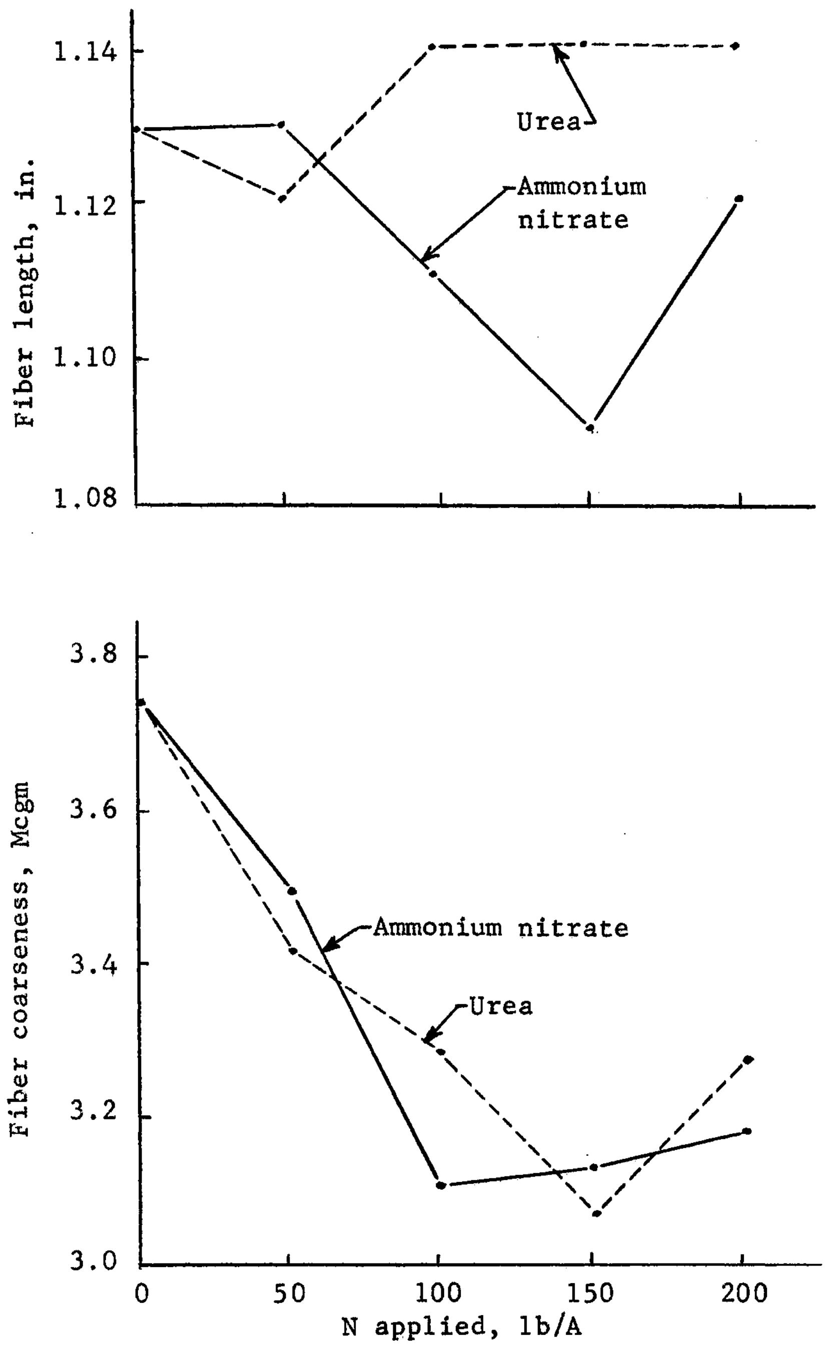


Figure 8. The Fiber Coarseness and Length of Cotton Lint from Irrigated Hollister Silty Clay Loam at Altus with Varying Rates of Urea and Ammonium Nitrate. Values are weighted for Composite Samples of the First and Second Harvests

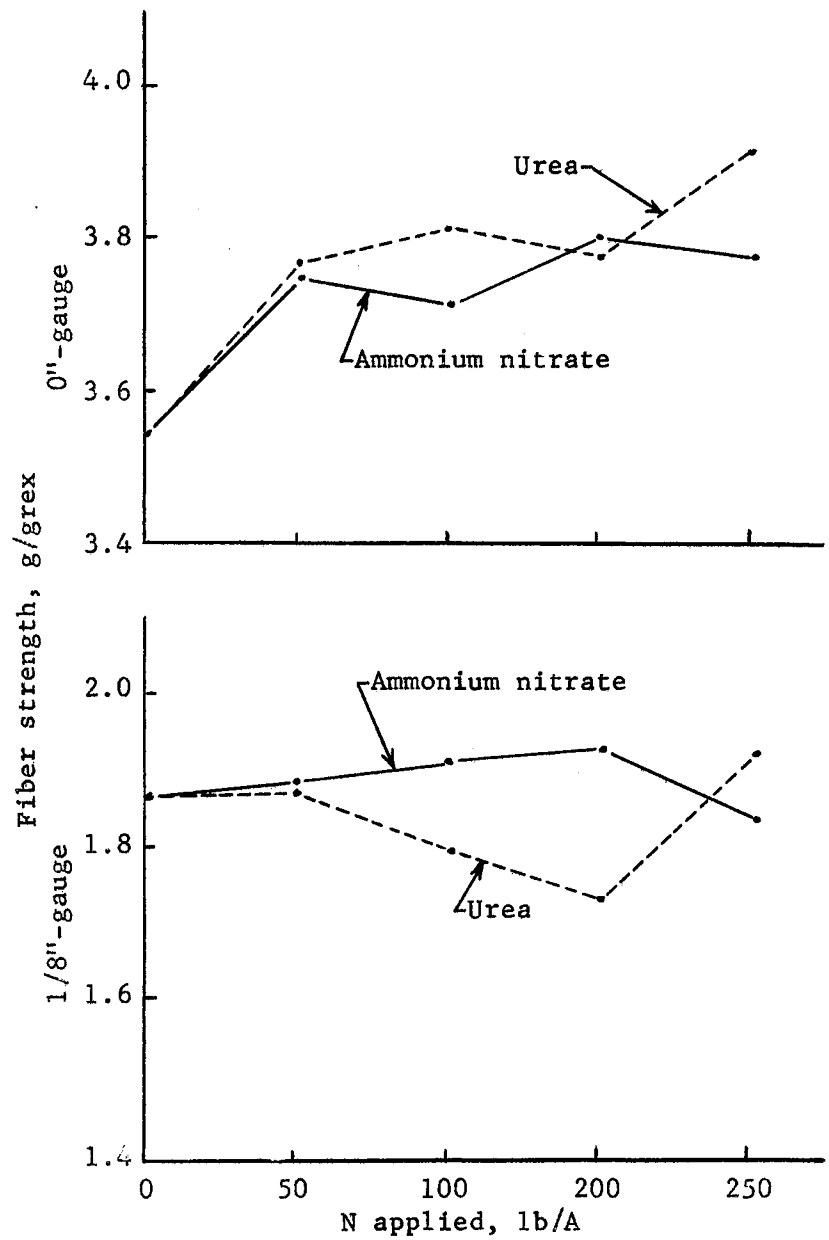


Figure 9. The Fiber Strength of Cotton Lint from Irrigated Hollister Silty Clay Loam at Altus with Varying Rates of Urea and Ammonium Nitrate. Values are Weighted for the Composite Samples of the First and Second Harvests

pattern was a typical quadratic response curve.

Seed yield. The cotton seed yield is shown in Figure 10. The patterns of seed yield response of cotton to N applications from urea and ammonium nitrate were substantially the same during the first and second harvests. However, the N rates significantly reduced the seed yield in the first and significantly increased seed yield in the second harvest. The significant differences in yields due to rates of N can be determined through Table XXII for the first and second harvests.

Greenhouse Studies

Experiment I - Comparison of Urea and Ammonium Nitrate

The results of this study are shown in Tables XXIII and XXIV. Although no significant differences in yields were noted between the two N sources, significant increases in yields due to N and P applications were obtained.

TABLE XXIII

THE EFFECTS OF VARYING RATES OF UREA AND AMMONIUM NITRATE AND PHOSPHATE ON THE DRY YIELD (g/POT) OF SUDANGRASS GROWN ON TALOKA SILT LOAM IN THE GREENHOUSE. VALUES ARE MEANS OF THREE REPLICATIONS

Nitrogen source	N rate (lb/A)	P rate (lb/A) 0	P rate (lb/A) 50
Urea	0	4.4	5.4
	60	6.6	8.1
	120	7.6	10.9
Ammonium nitrate	0	4.4	5.4
	60	7.2	8.6
	120	7.7	11.2

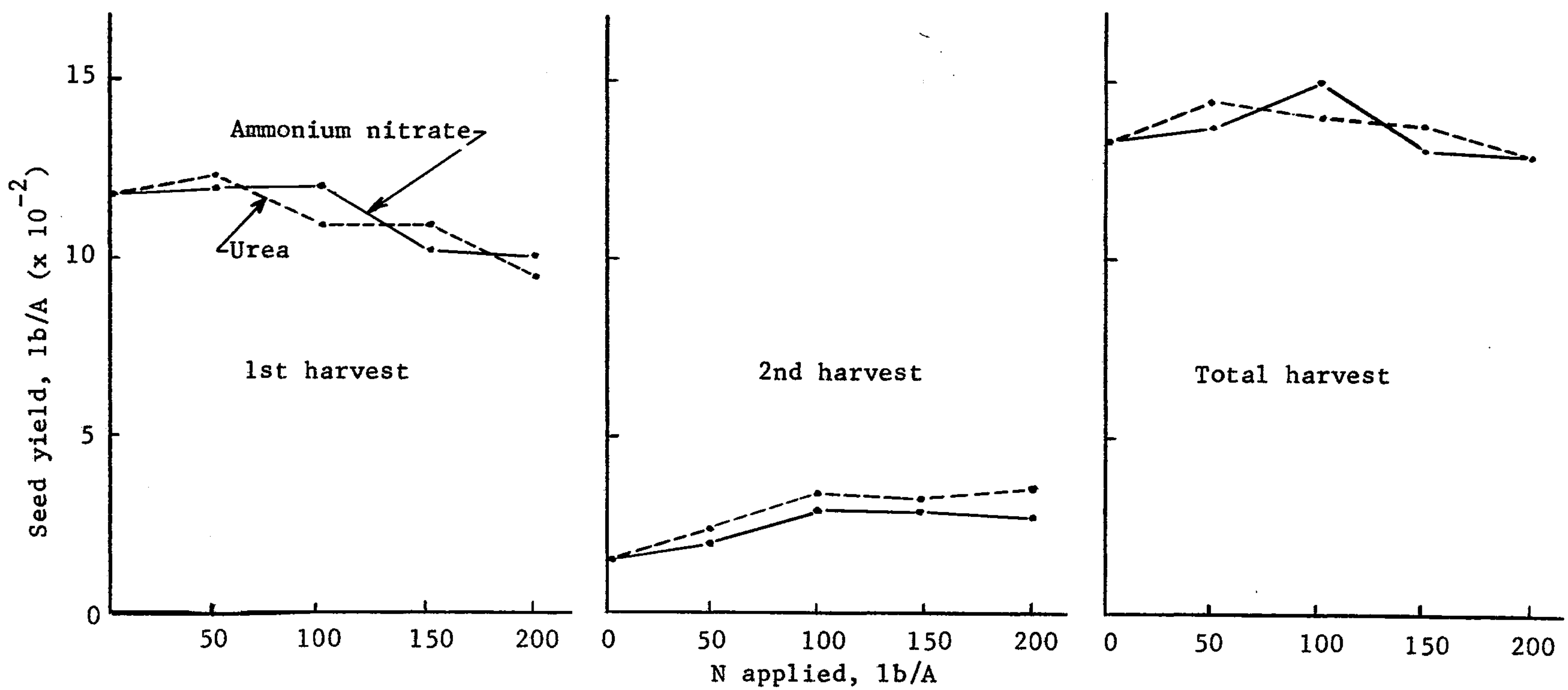


Figure 10. The Seed Yields of Cotton Grown on Irrigated Hollister Silty Clay Loam at Altus with Varying Rates of Urea and Ammonium Nitrate. Values are Means of Three Replications

TABLE XXIV

THE ANALYSIS OF VARIANCE AND LSR VALUES OF THE YIELD OF SUDANGRASS ON TALOKA SILT LOAM WITH VARYING RATES OF UREA, AMMONIUM NITRATE AND SUPERPHOSPHATE[1]

Source of variation	df	Mean square
Replications	2	0.480
N sources (N)	1	0.512
N rates (R)	2	60.140**
P rates (P)	1	31.920**
N x R	2	0.163
N x P	1	0.050
R x P	2	4.841*
N x R x P	2	0.005
Error	24	1.117

LSR values

	Number of pairs				
α level	2	3	4	5	6
5%	2.5	2.7	2.7	2.8	2.8
1%	3.4	3.6	3.7	3.7	3.8

[1]The mean yields are shown in Table XXIII.
*Significant at 5% level.
**Significant at 1% level.

In this experiment the yield response to N from both sources was almost a linear substantial increase from 0 through 120 lb/A of N. The significant differences in yields due to N and P applications can be determined through Tables XXIII and XXIV.

Experiment II - Urea N, P and Tannic Acid Applications

The dry matter yield of sudangrass obtained in this experiment is reported in Tables XXV and XXVI. There were significant yield responses to N and P applications but no significant yield effect was obtained from the applications of tannic acid. The significant yield differences between treatments can be determined through the mean

TABLE XXV

DRY MATTER YIELD (g/POT) OF SUDANGRASS GROWN ON TALOKA SILT LOAM TREATED WITH DIFFERENT RATES OF UREA N, PHOSPHATE AND TANNIC ACID. VALUES ARE MEANS OF THREE REPLICATIONS

lb/A		Tannic acid (lb/A)		
N	P	0	8.5	17.0
0	0	4.47	4.83	4.73
	50	5.90	5.30	5.93
60	0	6.57	6.77	6.90
	50	8.30	8.90	8.73
120	0	7.70	8.87	7.20
	50	11.00	10.90	10.07

TABLE XXVI

ANALYSIS OF VARIANCE AND LSR VALUES OF THE YIELD OF SUDANGRASS ON TALOKA SILT LOAM WITH VARYING AMOUNTS OF UREA, PHOSPHATE AND TANNIC ACID. THE MEAN YIELDS ARE REPORTED IN TABLE XXV

Source of variation	df	Mean square
Replications	2	0.133
Urea N levels (N)	2	76.670**
P levels (P)	1	48.167**
Tannic acid levels (T)	2	0.567
N x P	2	3.252**
N x T	4	1.104**
P x T	2	0.440
N x P x T	4	0.314
Error	34	0.250

LSR values

α level	Number of pairs 2	3	4	5	6
5%	1.15	1.21	1.25	1.27	1.30
1%	1.53	1.60	1.65	1.68	1.73

**Significant at 1% level.

yields in Table XXV and the LSR values in Table XXVI.

Experiment III - Urea and Ammonium Nitrate N and Tannic Acid on Rice at "Field Capacity" and Submerged Conditions

It was reported in the literature (Benoit and Starkey, 1968) that tannic acid from *Mimosa* bark considerably depressed urease activity *in vitro*. Hence, a study was conducted to determine if the effect of tannic acid on availability of urea N could be measured through plant growth. The results of this study are shown in Figures 11 and 12 and Tables XXVII and XXVIII.

First sampling (6 weeks old). The dry matter yields of rice in this experiment at six weeks are reported in Figure 11 while the analysis of variance is shown in Table XXVII. There were significant effects of N rates, N sources and tannic acid applications on the yield (Table XXVII). However, significant interactions between the variables made interpretation of the data difficult.

Second sampling. The dry matter yields of rice at 10 weeks are reported in Figure 12 and Table XXIX. The yields from the submerged soil were substantially higher than those of the soil at "field capacity."

Based on the yield response of rice, no conclusive evidence for the inhibition of urea conversion to available N by tannic acid was obtained from this study.

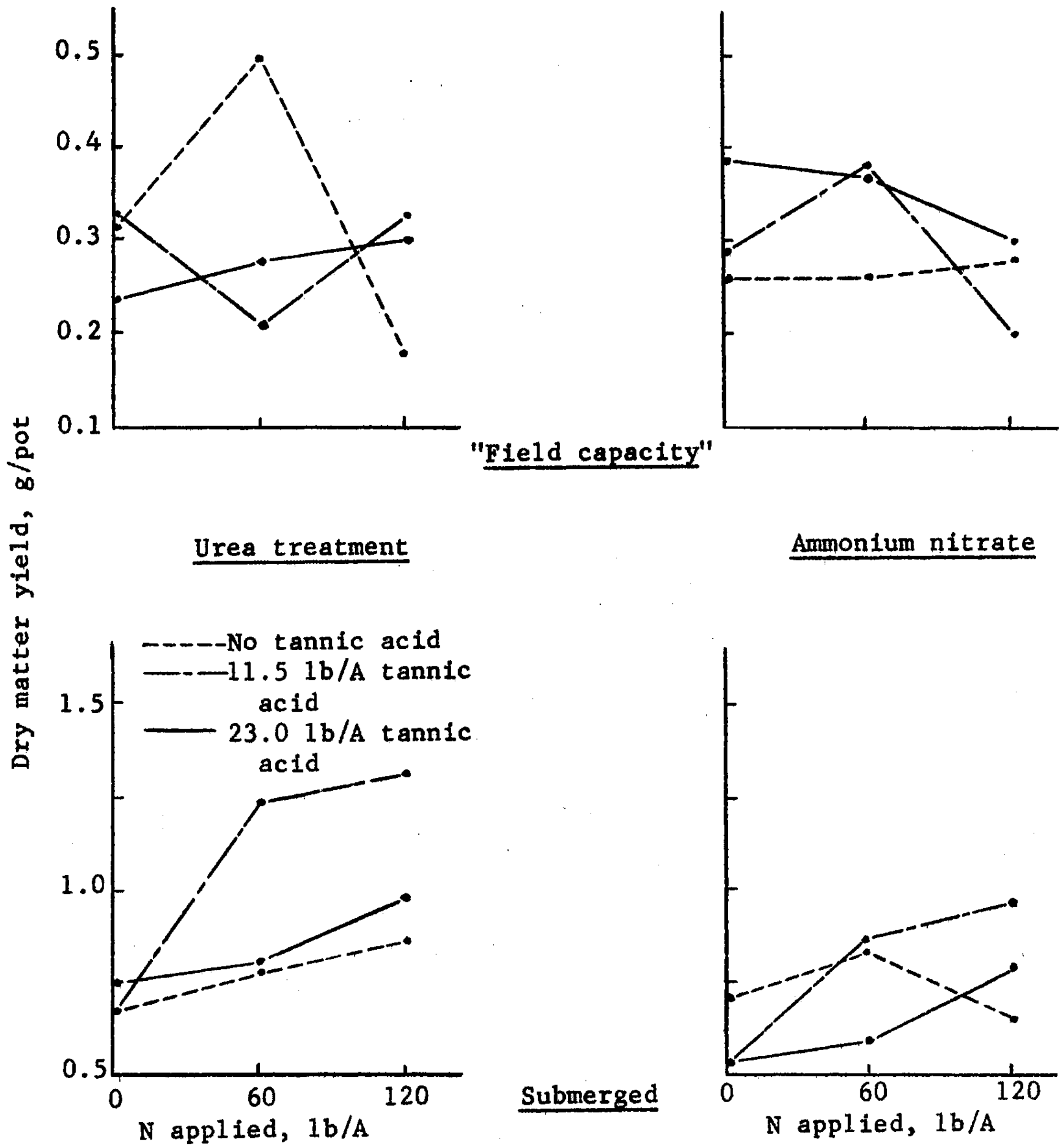


Figure 11. The Dry Matter Yields of Rice (Var. Saturn) at Six Weeks of Age on Taloka Silt Loam Treated with Urea, Ammonium Nitrate and Tannic Acid. Values are Means of Three Replications

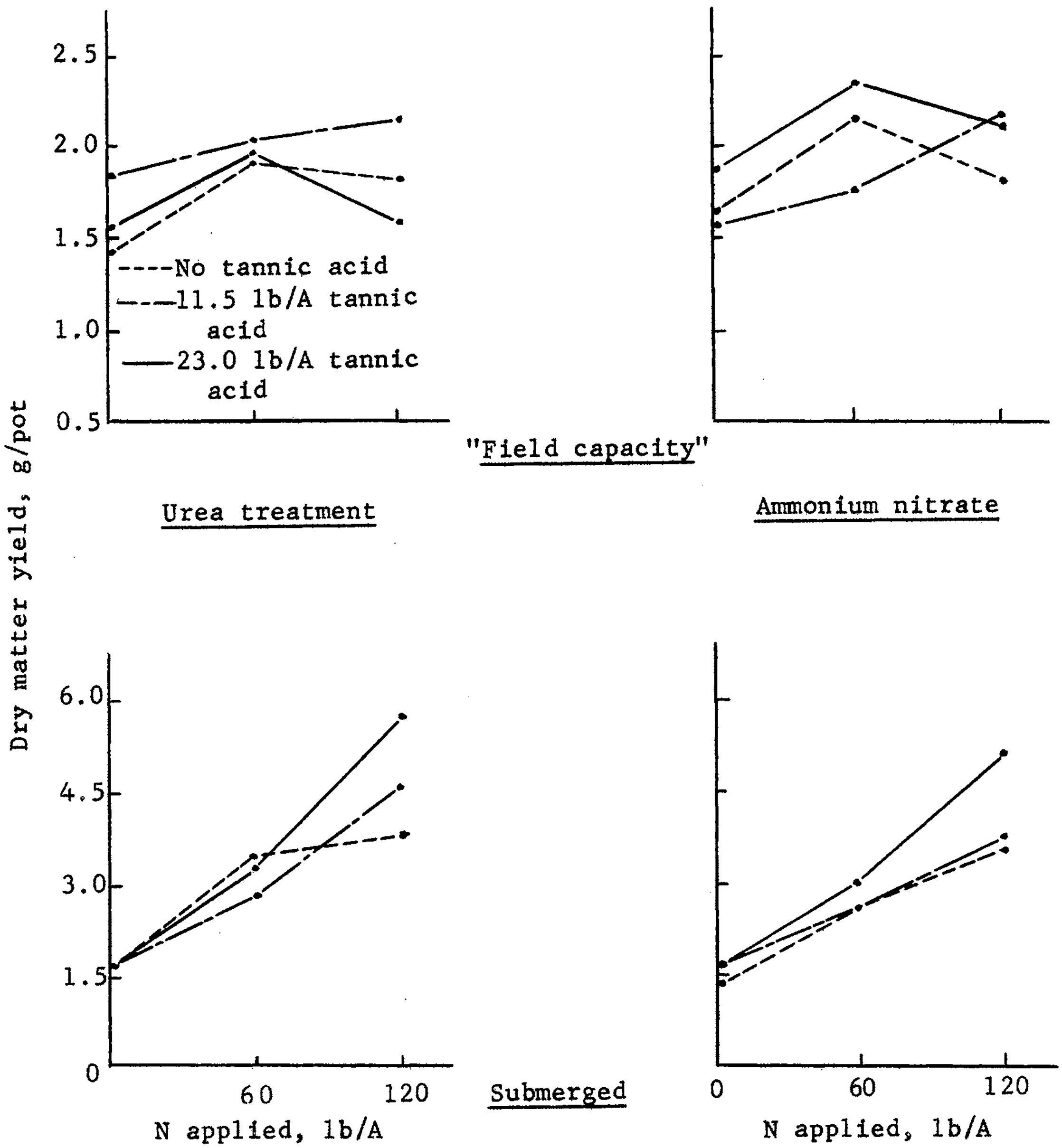


Figure 12. The Dry Matter Yields of Rice (Var. Saturn) at 10 Weeks of Age on Taloka Silt Loam Treated with Urea, Ammonium Nitrate and Tannic Acid. Values are Means of Three Replications

TABLE XXVII

ANALYSIS OF VARIANCE OF THE RICE YIELD AT TEN WEEKS OLD ON TALOKA SILT LOAM WITH VARIOUS RATES OF UREA, AMMONIUM NITRATE AND TANNIC ACID. THE MEAN YIELDS ARE SHOWN IN FIGURE 11

Source of variation	df	Mean square
Replications	2	0.02385833
Moisture level (W)	1	6.86548951**
N sources (N)	1	0.21960092**
N rates (R)	2	0.17425277**
Tannic acid rates (T)	2	0.08416944**
W x N	1	0.24940834**
W x R	2	0.23835648**
W x T	2	0.12351204**
N x R	2	0.01541759
N x T	2	0.01922871
R x T	4	0.06601389*
W x N x R	2	0.00417962
W x N x T	2	0.07538610**
W x R x T	4	0.06413703*
N x R x T	4	0.00539536
W x N x R x T	4	0.05335555
Error	70	0.01035452

*Significant at 5% level.
**Significant at 1% level.

Experiment IV - Urea and Ammonium Nitrate with Sudax on Spur Fine Sandy Loam

This experiment was conducted to determine the effects of urea and ammonium nitrate on the yield of Sudax on a soil that showed iron chlorosis in the previous crops.

"Field capacity" conditions. The data from this study are in Tables XXIX and XXX. Both N carriers had similar and significant effects on the yield of Sudax at four and six weeks. At seven weeks old the yields from the check and the N-treated pots were more or less the same (Tables XXIX and XXX).

TABLE XXVIII

ANALYSIS OF VARIANCE OF THE RICE YIELD AT SIX WEEKS OLD ON TALOKA SILT LOAM WITH VARIOUS RATES OF UREA, AMMONIUM NITRATE AND TANNIC ACID. THE MEAN YIELDS ARE SHOWN IN FIGURE 12

Source of variation	df	Mean square
Replications	2	0.0520176
Moisture levels (W)	1	34.8502083**
N sources (N)	1	0.5029342
N rates (R)	2	22.2626509**
Tannic acid rates (T)	2	1.4294453**
W x N	1	1.8907788**
W x R	2	14.8218361**
W x T	2	1.1282861**
N x R	2	0.1552954
N x T	2	0.1823732
R x T	4	0.6742592*
W x N x R	2	0.3323064
W x N x T	2	0.2089175
W x R x T	4	0.8644638*
N x R x T	4	0.0198342
W x N x R x T	4	0.1302303
Error	70	0.1175641

*Significant at 5% level.
**Significant at 1% level.

TABLE XXIX

THE DRY MATTER YIELD (g/POT) OF SUDAX ON SPUR FINE SANDY LOAM TREATED WITH 100 lb/A N FROM UREA AND AMMONIUM NITRATE. VALUES ARE MEANS OF FIVE REPLICATIONS

Age at sampling (weeks)	N source		
	Check	Urea	Ammonium nitrate
4	0.78	0.84	0.90
6	1.96	2.04	2.30
7	4.36	4.34	4.80

TABLE XXX

ANALYSIS OF VARIANCE AND LSR VALUES OF THE SUDAX YIELD ON SPUR FINE SANDY LOAM TREATED WITH 100 lb/A N FROM UREA AND AMMONIUM NITRATE. THE MEAN YIELDS ARE REPORTED IN TABLE XXIX

Source of variation	df	Mean square
Replications	4	0.8891*
Ages at sampling (A)	2	51.8580**
N sources (N)	2	0.3980
A x N	4	0.0580
Error	36	0.2681

LSR values

α level	Number of pairs 2	3	4	5	6
5%	1.22	1.28	1.32	1.35	1.37
1%	1.61	1.70	1.76	1.79	1.82

*Significant at 5% level.
**Significant at 1% level.

"Field capacity" and saturated conditions. In this study the plants that were saturated showed marked chlorosis three days after saturation whereas the plants that were maintained at "field capacity" were not as chlorotic. The saturated pots were allowed to revert to "field capacity" through evapo-transpiration. When the plants were six weeks old in both moisture schemes they were harvested. The yield data are reported in Tables XXXI and XXXII. The analysis of variance (Table XXXII) showed that the plants that were saturated for three days had significantly higher yields than those that were maintained at "field capacity" throughout the experiment. This yield increase was obtained despite the chlorosis shown during the time of saturation. Since this soil had previous crops showing iron chlorosis the saturation period

TABLE XXXI

THE DRY MATTER YIELD (g/POT) OF SUDAX ON SPUR FINE SANDY LOAM WITH UREA AND AMMONIUM NITRATE (AND CHECK) AT 100 lb/A N AND AT TWO MOISTURE TREATMENTS. VALUES ARE MEANS OF FIVE REPLICATIONS

Moisture treatment	N source		
	Check	Urea	Ammonium nitrate
"Field capacity" (FC)	2.10	2.17	2.53
FC-saturation-FC	2.37	2.80	2.69

TABLE XXXII

ANALYSIS OF VARIANCE AND LSR VALUES OF THE SUDAX YIELD ON SPUR FINE SANDY LOAM WITH 100 lb/A N FROM UREA AND AMMONIUM NITRATE. THE MEAN YIELDS ARE SHOWN IN TABLE XXXI

Source of variation	df	Mean square
Replications	2	0.0405
N sources (N)	2	0.3505
Moisture treatments (W)	1	0.7022*
N x W	2	0.1039
Error	10	0.0939

LSR values

α level	Number of pairs				
	2	3	4	5	6
5%	0.78	0.82	0.84	0.86	0.87

*Significant at 5% level.

may have reduced the soil iron and made it more available to the plants, hence the increasing yield.

Experiment V - IR 8 Rice with Urea and Ammonium Nitrate

In this experiment N from urea and ammonium nitrate was applied at 100 lb/A to 70 kg air dry Taloka silt loam soil from Muskogee. The soil was put into 14-gallon stainless steel cans. Samplings at various ages were made and the yield data are reported in Table XXXIII and Figure 13.

TABLE XXXIII

ANALYSIS OF VARIANCE AND LSR VALUES OF THE IR 8 RICE YIELD (ON TALOKA SILT LOAM) GROWN IN THE GREENHOUSE WITH 100 lb/A N FROM UREA AND AMMONIUM NITRATE. THE MEAN YIELDS ARE SHOWN IN THIS TABLE AND IN FIGURE 13

Source of variation	df	Mean square
Replications	2	11.6591
Ages at sampling (A)	4	11852.0378**
N sources (N)	2	71.4469**
A x N	8	16.2616
Error	28	6.6203

LSR values

α level	Number of pairs 2	3	4	5	6	7	8	9
5%	6.1	6.4	6.6	6.7	6.9	6.10	6.11	6.12
1%	8.2	8.5	8.8	9.0	9.1	9.10	9.20	9.30

Mean yields, g/pot

N source	Age at sampling, wk. 3	6	13	16	20
Check	1.0	4.0	15.8	27.8	39.7
Urea	1.1	5.5	20.2	32.2	51.0
Ammonium nitrate	1.2	4.8	19.8	31.8	43.6

**Significant at 1% level.

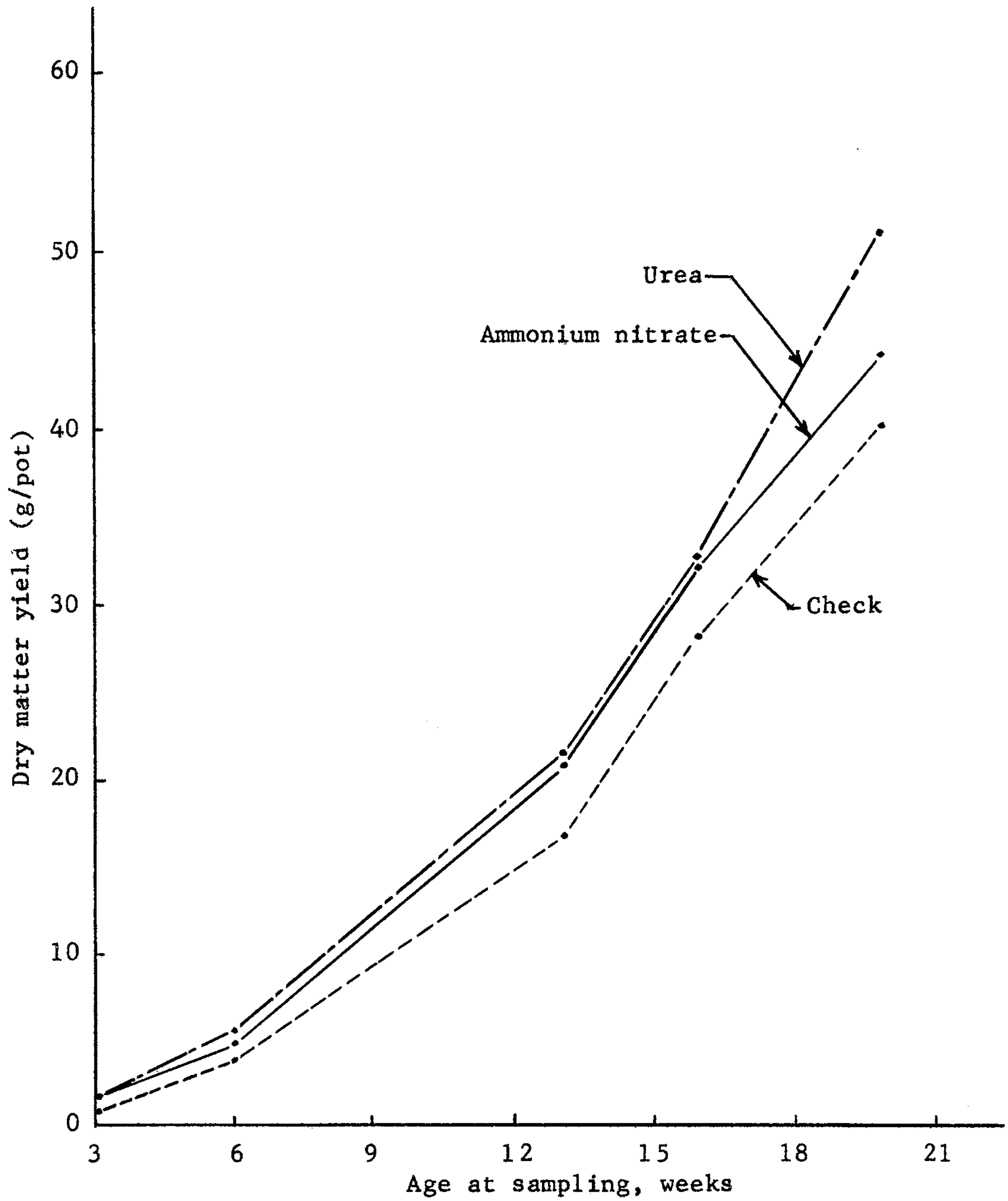


Figure 13. The Dry Matter Yield of IR 8 Rice Grown on Taloka Silt Loam Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

Figure 13 shows that the growth of the IR 8 rice plants was still increasing sharply at 20 weeks old. The yield response to N applications from urea and ammonium nitrate were practically the same up to 16 weeks. From 16 to 20 weeks of age the yield of the urea pots increased significantly more than that of the ammonium nitrate pots. The check pots, though yielding significantly lower than the N-treated pots, showed a similar pattern of growth as the yield curve of the ammonium nitrate treatment.

The significant reduction in rate of yield increase in ammonium nitrate pots, compared to the yield increase in the urea treatments at 20 weeks, could be due to a decrease in the amount of available N as a consequence of reducing conditions in the submerged soil. The data on total N in the rice plants and the redox potential measurement of the submerged soil on which the rice was grown will bear this out.

Total N. Total N in the rice plants was determined at the ages of 6, 13, 16 and 20 weeks. The total N is reported in Figure 14 and in Table XXXIV. The analysis of rice plants grown in the check pots showed a linear increase in total N from 6 to 16 weeks. From 16 to 20 weeks the rate of increase in the total N of the plants in the check pots was reduced.

The pattern of total N accumulation in rice plants of the urea pots (Figure 14) was a rapid and almost linear increase from 6 to 20 weeks. The total N in the rice plants in ammonium nitrate pots had also a rapid increase from 6 to 13 weeks and then the rate of increase was reduced from 13 to 20 weeks. It is interesting to note in Figure 14 that urea continued to provide N to the plants up to 20 weeks while ammonium nitrate almost stopped providing N after 13 weeks.

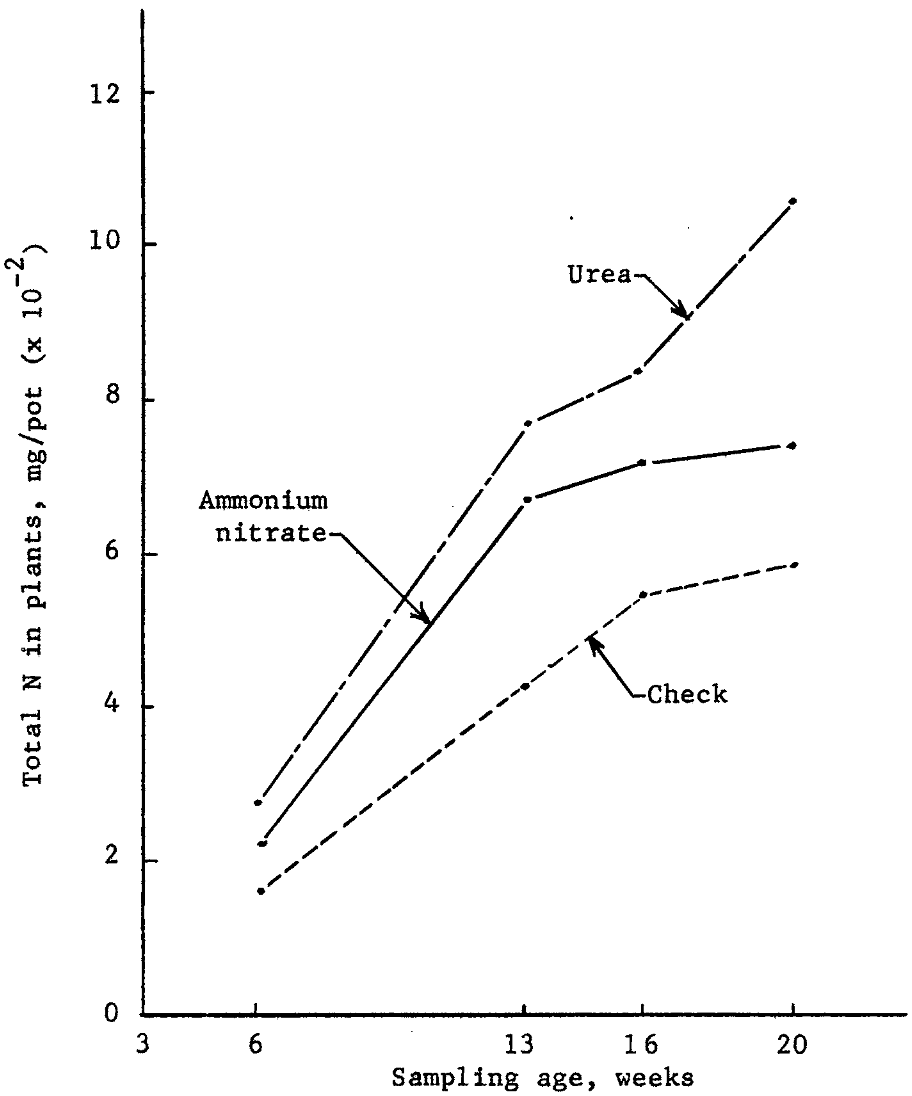


Figure 14. The Total N (mg/pot) of IR 8 Rice on Taloka Silt Loam Under Continuous Submergence with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

TABLE XXXIV

THE ANALYSIS OF VARIANCE, MEAN N CONTENTS AND LSR VALUES FOR THE TOTAL N IN IR 8 RICE PLANTS GROWN ON TALOKA SILT LOAM WITH 100 lb/A N FROM UREA AND AMMONIUM NITRATE. THE MEAN N CONTENTS ARE SHOWN IN FIGURE 14

Source of variation	df	Mean square
Replications	2	2636.1332
N sources (N)	2	282220.1333**
Sampling ages (A)	3	581321.2146**
N x A	6	20241.7982**
Error	22	3565.8500

Mean N contents, mg/pot

N source	Sampling age, weeks 6	13	16	20
Check	157.6	427.1	552.7	591.8
Urea	279.7	772.6	839.0	1064.5
Am. nitrate	226.3	677.4	715.0	742.7

LSR values

α level	Number of pairs 2	3	4	5	6	7	8	9
5%	144.1	150.9	155.7	158.7	161.1	162.4	163.6	165.5
1%	196.1	204.6	210.3	214.2	217.9	220.0	222.2	224.0

**Significant at 1% level.

The significant differences in yields due to N sources and ages at sampling can be determined through Table XXXIV. It is interesting to note in Figures 13 (dry matter yield) and 14 (total N content) that in the ammonium nitrate pots the rate of increase in N uptake started decreasing at 13 weeks but the rate of increase in dry matter yield was not reduced until three weeks later.

Redox potential measurements. To determine the redox status in the submerged Taloka silt loam as the rice plants were growing, the redox potential was measured. The results of the measurements are indicated in Figure 15. In the check pots the redox potential approached reducing conditions from 2 to 10 cm deep at 3 weeks. The reducing potential became apparent at 6 weeks and continued to increase until the 16th week. The reducing potential also increased with depth from 2 to 10 cm.

In the urea pots the reducing potential was rapidly approaching maximum reducing conditions 3 weeks after submergence of the soil and the reduction increased with depth from 2 to 10 cm until the 16th week. On the other hand, the ammonium nitrate pots still had an oxidizing potential at 2 cm deep at 3 weeks. At this period, the reducing conditions in the ammonium nitrate pots became apparent only at 4 cm depth. At 16 weeks the reducing potential in the ammonium nitrate pots reached maximum at all depths.

These data and those shown in Figures 13 and 14 indicate that although urea promoted reducing conditions more rapidly, its availability to the rice plant was not adversely affected. On the other hand, the availability of N from ammonium nitrate was diminished by reducing conditions in the soil due probably to the loss of NO_3 by reduction into gaseous forms.

Incubation Studies

The rate of release of N from urea and ammonium nitrate was studied on Taloka silt loam and Brewer clay loam without plants on the soil. The results are categorized into "total" N (NH_4-N plus NO_3-N), NH_4-N, and NO_3-N. Three moisture conditions were included in the study ("field

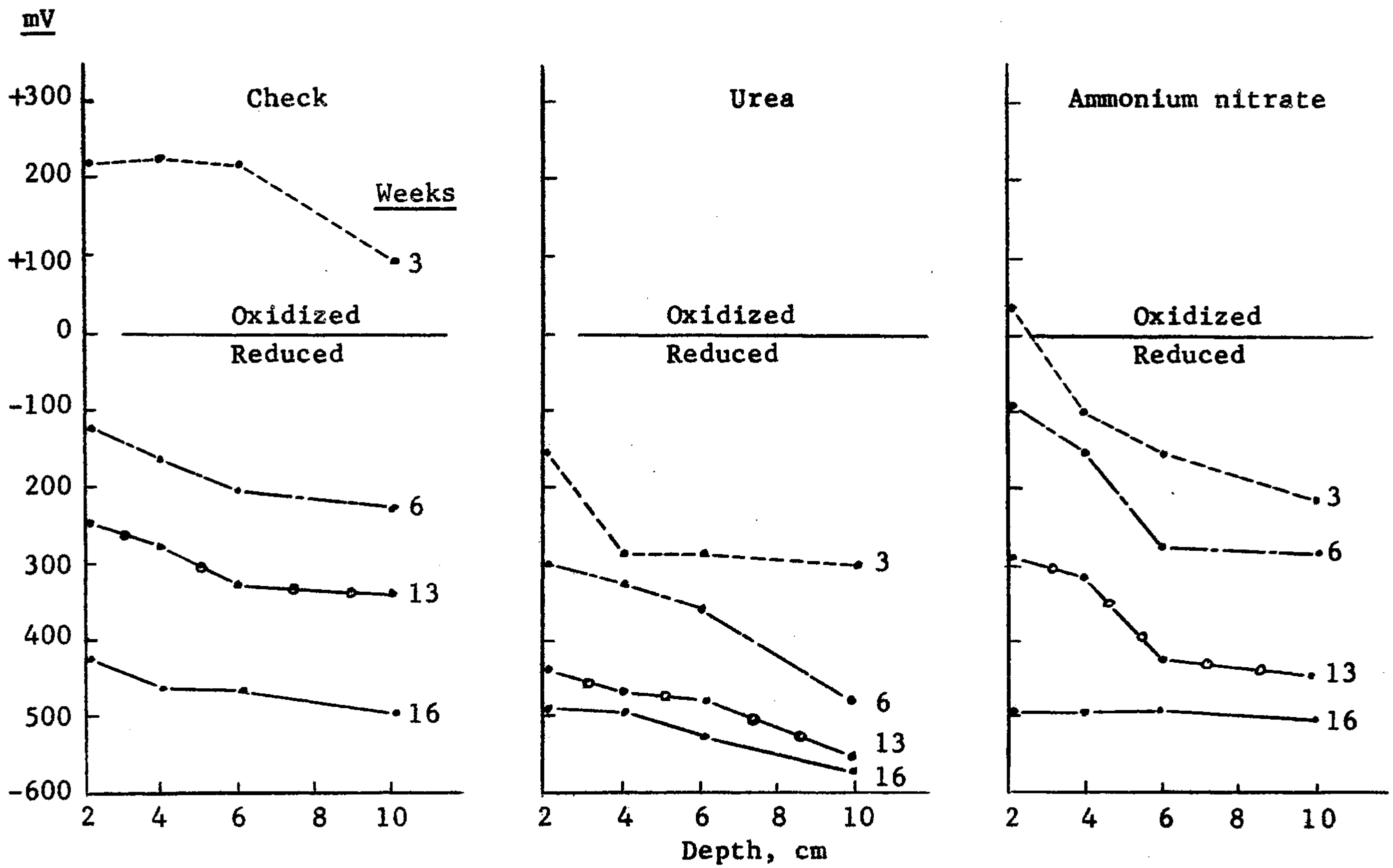


Figure 15. The Redox Potential (mV) of the Submerged Taloka Silt Loam Soil with Growing Rice Fertilized with 100 lb/A N from Urea and Ammonium Nitrate Values are Means of Three Replications

TABLE XXXV

THE ANALYSIS OF VARIANCE, MEAN VALUES AND LSR OF "TOTAL" N FROM TALOKA SILT LOAM AND BREWER CLAY LOAM SOILS INCUBATED WITH 100 ppm N FROM UREA AND AMMONIUM NITRATE FOR VARIOUS INCUBATION PERIODS AT "FIELD CAPACITY," SATURATION AND SUBMERGENCE. THE MEAN VALUES ARE SHOWN IN FIGURES 16 AND 17

Source of variation	df	Mean square
Replications	2	108.5988
Soils (S)	1	12613.4739**
N sources (N)	2	103462.0319**
Moisture levels (M)	2	20446.0811**
Incubation periods (I)	3	4204.4913**
S x N	2	22972.8803**
S x M	2	6712.8089**
S x I	3	442.6000**
N x M	4	3409.9019**
N x I	6	295.5928**
M x I	6	1326.9545**
S x N x M	4	2267.4623**
S x N x I	6	647.1164**
S x M x I	6	787.7092**
N x M x I	12	606.2002**
S x N x M x I	12	181.1866**
Error	142	46.1310

Mean "total" N

Soil	N source	Moisture level	Incubation (days) 5	10	20	40
Taloka s. l.	Check	FC	12.1	15.0	29.4	34.2
		Sat.	8.7	26.5	26.4	39.6
		Sub.	7.6	7.6	7.8	13.7
	Urea	FC	48.0	63.1	78.8	117.3
		Sat.	46.9	64.6	71.5	83.4
		Sub.	49.1	56.2	59.2	74.6
	Am. nit.	FC	140.7	148.4	134.6	120.5
		Sat.	134.3	125.1	128.6	136.7
		Sub.	110.1	121.0	117.6	128.5

Continued next page

TABLE XXXV Continued:

Soil	N source	Moisture level	Incubation (days) 5	10	20	40
Brewer c. l.	Check	FC	13.7	14.2	19.6	33.7
		Sat.	5.7	9.7	33.2	47.1
		Sub.	9.6	10.8	6.9	7.6
	Urea	FC	53.9	85.4	90.4	113.6
		Sat.	32.0	13.3	26.6	48.2
		Sub.	62.5	20.4	15.3	20.0
	Am. nit.	FC	97.6	98.7	106.4	119.2
		Sat.	30.3	27.1	62.5	88.4
		Sub.	38.5	11.4	10.3	17.2

LSR values

α level	Number of pairs 2	3	4	5	6	7	8	9	10	11	12
5%	15.3	16.1	16.6	17.0	17.2	17.6	17.8	18.0	18.1	18.2	18.3
1%	20.1	20.9	21.5	21.9	22.3	22.6	22.8	23.0	23.2	23.3	23.4

**Significant at 1% level.

capacity," saturation, and submergence).

"Total" N

Figures 16 and 17 show the "total" N (both NH_4- and NO_3- were extracted by water, one hour shaking in a soil:water ratio of 1:2.5). Table XXXV indicates the analysis of variance of the data shown in Figures 16 and 17. The release of N from urea and ammonium nitrate shows different patterns in each soil, especially under submerged conditions.

"Field capacity." At about "field capacity" "total" N in the urea-treated soil increased from 5 to 40 days of incubation for both soils. However, the release was much more rapid in the Taloka silt loam than in the Brewer clay loam.

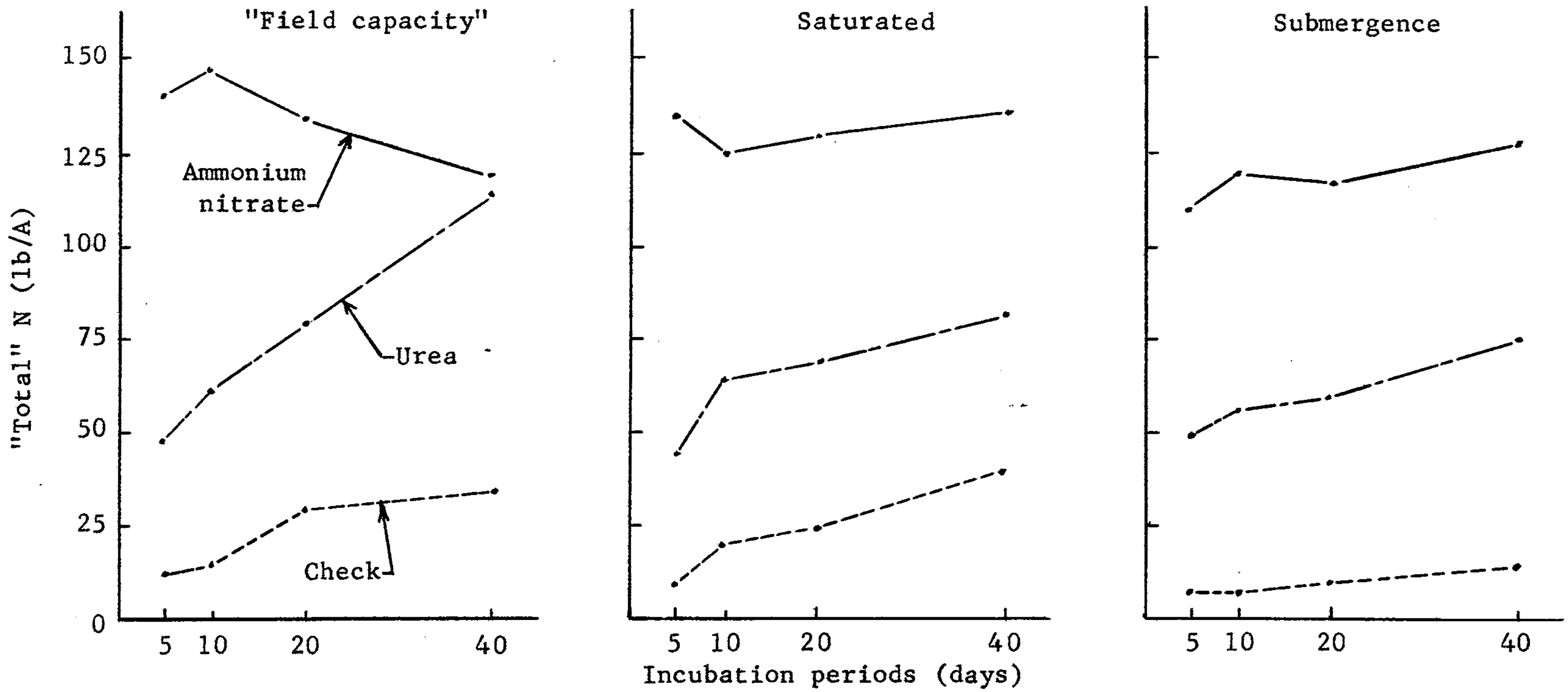


Figure 16. The Effects of Varying Moisture Conditions and Incubation Periods on the Water-soluble "Total" N (NH_4-N + NO_3-N) in Taloka Silt Loam Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

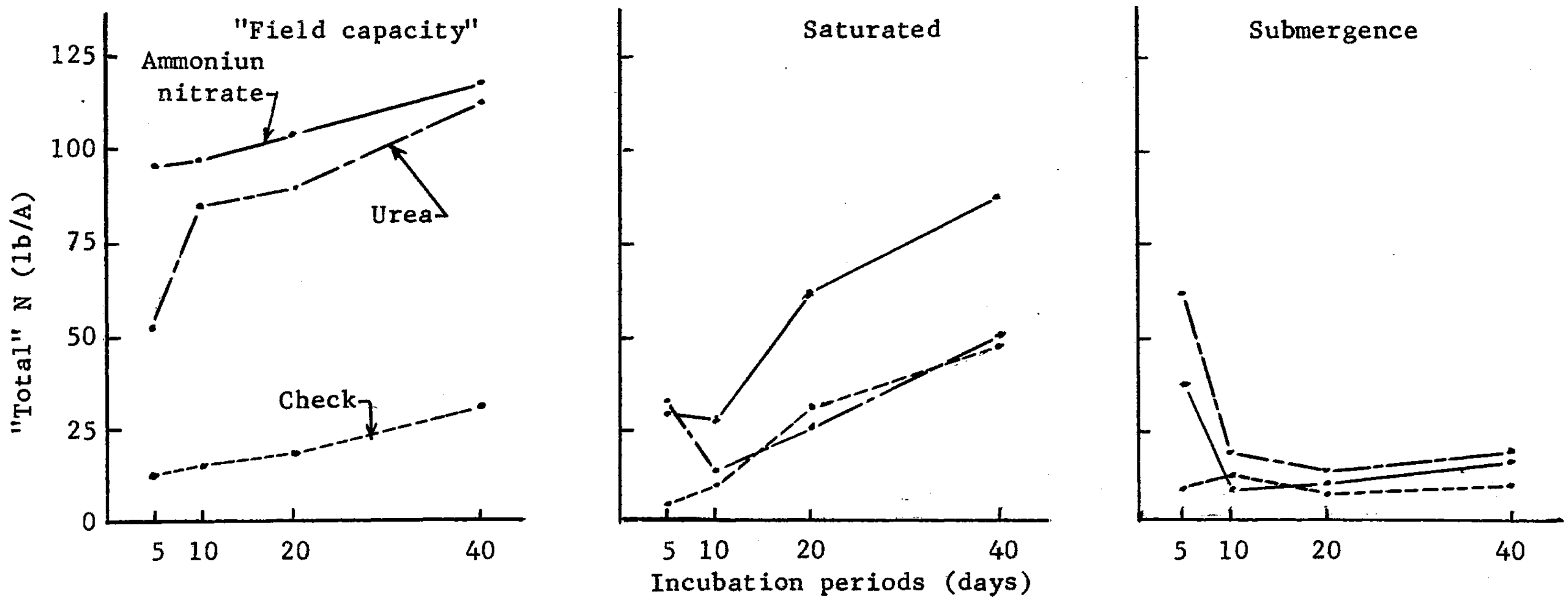


Figure 17. The Effects of Varying Moisture Conditions and Incubation Periods on the Water-soluble "Total" N (NH_4-N + NO_3-N) in Brewer Clay Loam Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

In the ammonium nitrate treatment, Taloka silt loam showed a decreasing trend in "total" N from 5 to 40 days of incubation. Brewer clay loam, on the other hand, showed an increasing amount of "total" N from 5 to 40 days of incubation. In the check, both soils showed increasing but low amounts of "total" N.

Saturated condition. When the two soils were kept at saturation the Brewer clay loam showed a decrease in "total" N for both urea and ammonium nitrate from 5 to 10 days (Figure 17) followed by a continued increase from 10 to 40 days. In the Taloka silt loam (Figure 16) the amount of "total" N in the ammonium nitrate treatment decreased from 5 to 10 days and then increased from 10 to 40 days. It is of interest to note that the amount of "total" N from urea in the Brewer clay loam at saturation was not substantially different from that of the check at 10 to 40 days.

Submerged condition. Under this condition, while the "total" N in the Taloka silt loam increased slightly from 5 to 40 days, that of the Brewer clay loam decreased abruptly from 5 to 10 days, regardless of N carrier. This increase in "total" N in the Taloka silt loam up to 40 days of submergence was due mainly to an increase in NO_3-N as will be discussed later. In the Brewer clay loam under submergence, the amount of "total" N was practically the same for the check and the other two N carriers (Figure 17).

In general, the amount of "total" N in Taloka silt loam, under all moisture conditions and incubation periods, was highest for ammonium nitrate, followed by urea, and lowest in the check. In the Brewer clay loam under "field capacity" and at all incubation periods the "total" N was highest from ammonium nitrate, followed by urea, and the lowest was in the check. In the saturated Brewer soil incubated 10 to 40 days the "total" N was highest from ammonium nitrate and the same for the urea and check treatments. When submerged, "total" N in the Brewer clay loam was highest from urea, followed by ammonium nitrate, and the lowest was in the check.

NH_4-N Release

The data for NH_4-N of both soils are reported in Figures 18 and 19 for Taloka silt loam and Brewer clay loam, respectively. The analysis of variance of the data in the two figures is shown in Table XXXVI.

In both soils, the check had practically no increase in NH_4-N throughout the incubation period of 40 days and the amount of this form of water-soluble N was only about 5 ppm, or lower, under all moisture conditions. The general trend for both soils was a decreasing amount of NH_4-N from 5 to 40 days regardless of N carrier and moisture condition. However, the rates of decrease in NH_4-N varied with the soil.

"Field capacity." At this moisture condition, there was no substantial change in the amount of NH_4-N from urea in the Taloka silt loam over time. On the other hand, the amount of NH_4-N in the ammonium nitrate treatment decreased abruptly from 5 to 10 days of incubation. After 10 days this decrease became slow and gradual up to 40 days. Thus at "field capacity" of the Taloka silt loam, the amount of NH_4-N from ammonium nitrate was significantly greater than that of urea only at 5 days of incubation. For periods longer than 5 days, the NH_4-N released from both N carriers was almost the same.

In the Brewer clay loam, the trends in release of NH_4-N was the same for both N carriers. The pattern was also an abrupt decrease

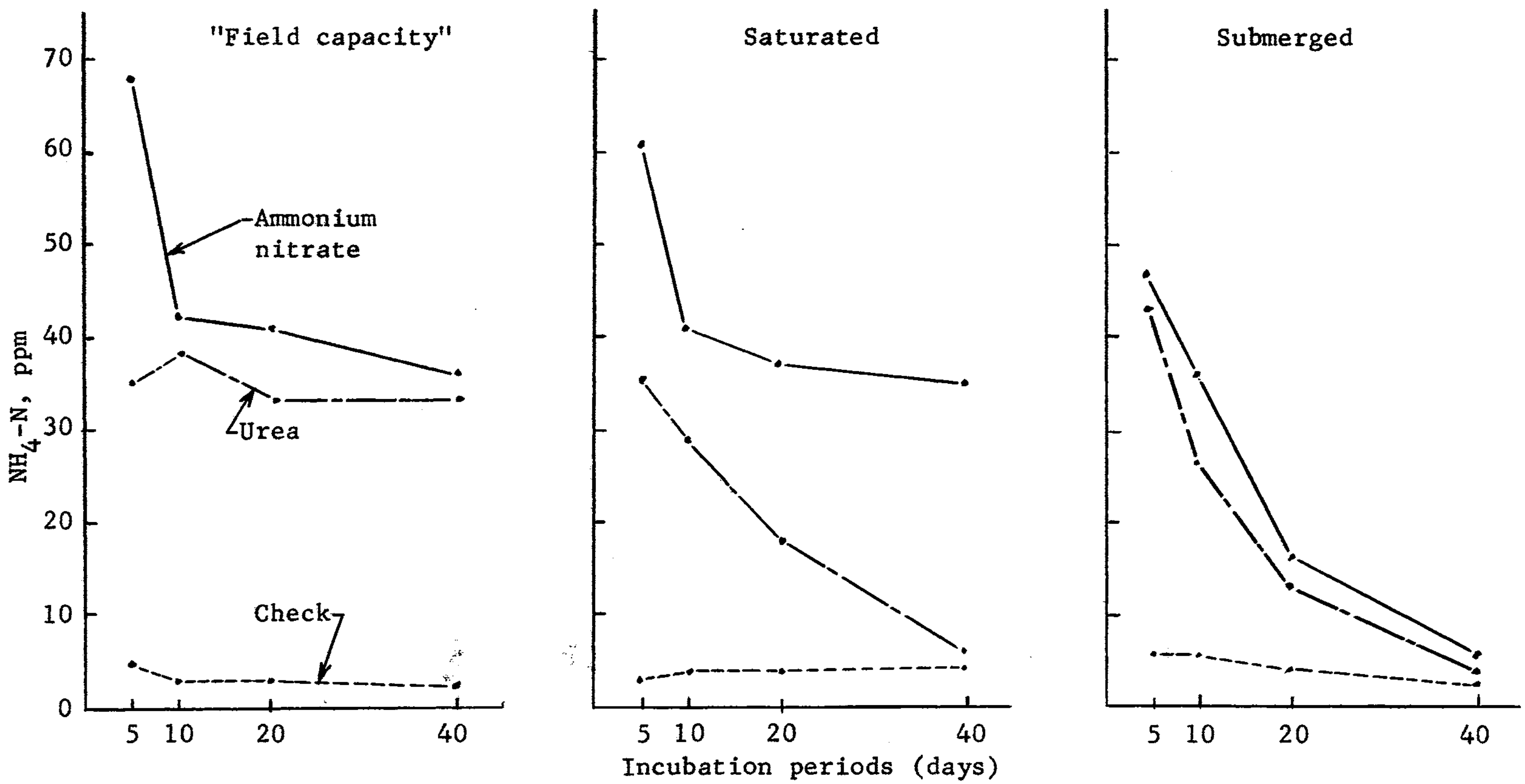


Figure 18. The Amount of Water-soluble NH_4-N in Taloka Silt Loam at Various Incubation Periods and Moisture Levels. The Soil Was Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

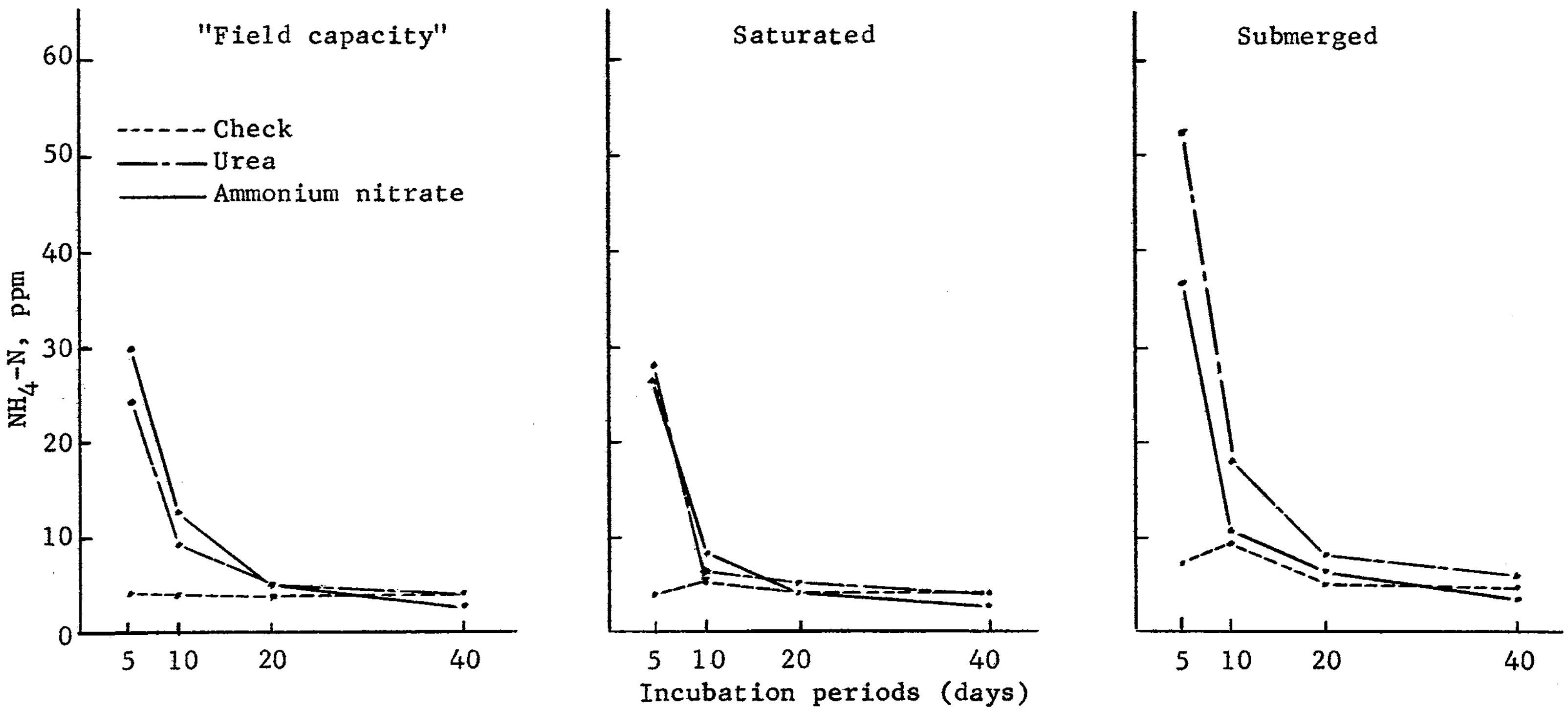


Figure 19. The Amount of Water-soluble NH_4-N in Brewer Clay Loam at Various Incubation Periods and Moisture Levels. The Soil Was Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

TABLE XXXVI

THE ANALYSIS OF VARIANCE, MEAN VALUES AND LSR OF NH_4-N FROM UREA AND AMMONIUM NITRATE IN TALOKA SILT LOAM AND BREWER CLAY LOAM AT VARIOUS INCUBATION PERIODS WITH 100 lb/A N. THE MEAN VALUES ARE SHOWN IN FIGURES 18 and 19

Source of variation	df	Mean square
Replications	2	11.8301
Soils (S)	1	8651.3380**
N sources (N)	2	8974.9254**
Moisture levels (M)	2	237.9329**
Incubation periods (I)	3	4378.2544**
S x N	2	3628.0656**
S x M	2	1314.2538**
S x I	3	69.8790**
N x M	4	342.8800**
N x I	6	932.8939**
M x I	6	186.0064**
S x N x M	4	316.0858**
S x N x I	6	116.2886**
S x M x I	6	58.4768**
N x M x I	12	126.9393**
S x N x M x I	12	29.6355**
Error	142	8.9917

Mean NH_4-N

Soil	N source	Moisture level	Incubation (days) 5	10	20	40
Taloka s. l.	Check	FC	5.0	3.4	3.2	2.7
		Sat.	3.3	4.0	4.0	4.3
		Sub.	5.7	5.6	4.0	3.9
	Urea	FC	35.7	38.5	34.1	34.2
		Sat.	40.8	29.4	18.3	6.1
		Sub.	43.4	26.8	13.5	3.0
	Am. nitrate	FC	68.4	47.8	41.5	36.9
		Sat.	61.2	41.2	37.9	35.2
		Sub.	47.6	36.4	16.5	6.0

Continued next page

TABLE XXXVI Continued:

Soil	N source	Moisture level	Incubation (days) 5	10	20	40
Brewer c. l.	Check	FC	4.5	4.6	4.4	4.4
		Sat.	4.5	6.0	4.3	4.1
		Sub.	7.9	9.9	5.2	4.7
	Urea	FC	24.4	9.8	5.1	4.3
		Sat.	28.4	6.9	5.0	4.5
		Sub.	58.0	18.2	7.9	5.3
	Am. nitrate	FC	30.1	13.1	5.4	3.1
		Sat.	27.1	8.2	4.3	3.3
		Sub.	37.1	10.5	6.0	3.1

LSR values

α level	Number of pairs 2	3	4	5	6	7	8	9	10	11	12
5%	6.8	7.1	7.4	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3
1%	8.9	9.3	9.6	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5

**Significant at 1% level.

from 5 to 10 days, followed by a low rate of decrease from 10 to 20 days, and practically no more decrease from 20 to 40 days.

Saturated condition. In both soils and for both N carriers, the amount of NH_4-N at saturated condition decreased as the incubation period lengthened. In the Taloka silt loam soil the decrease from 5 to 10 days was more abrupt for the ammonium nitrate than for urea. In the same soil, NH_4-N from ammonium nitrate remained more or less the same from 20 to 40 days whereas that of the urea, continued to decrease substantially from 5 to 40 days.

In the Brewer clay loam the pattern of NH_4-N release was the same for both carriers and this was an abrupt decrease from 5 to 10 days followed by a very slight decreasing trend from 10 to 40 days.

Submerged condition. In both soils the pattern of NH_4-N release was the same for both N carriers in general. This trend was a continued rapid decrease from 5 to 40 days in the Taloka silt loam. In the Brewer clay loam, the decrease was drastic from 5 to 10 days, gradual from 10 to 20 days, and practically nil from 20 to 40 days.

It may be pointed out that in the Taloka silt loam the quantity of NH_4-N was significantly higher in the ammonium nitrate treatment than that of urea in 5 days of incubation at "field capacity" and at all incubation periods of saturated condition. Under submergence, the amount of NH_4-N from both N carriers was more or less the same at all incubation periods.

In the Brewer clay loam, the amount of NH_4-N from both N carriers was highest at submergence during the incubation period of 5 days, and lowest from 20 to 40 days.

NO_3-N Release

The pattern of NO_3-N release from both N carriers and in both soils was increasing with incubation period and under all moisture conditions except that of ammonium nitrate at "field capacity" in Taloka silt loam (Figures 20 and 21, and Table XXXVII). This pattern was a drastic increase from 5 to 10 days, and then a decrease from 10 to 40 days. It is of interest to note that in Taloka silt loam the moisture condition did not drastically influence the amount and pattern of NO_3-N release (except at "field capacity" for ammonium nitrate). The increasing NO_3-N from 5 to 40 days of incubation was unexpected because the writer conceived that with increasing submergence denitrification would proceed to convert NO_3 to gaseous forms of N. These unexpected results

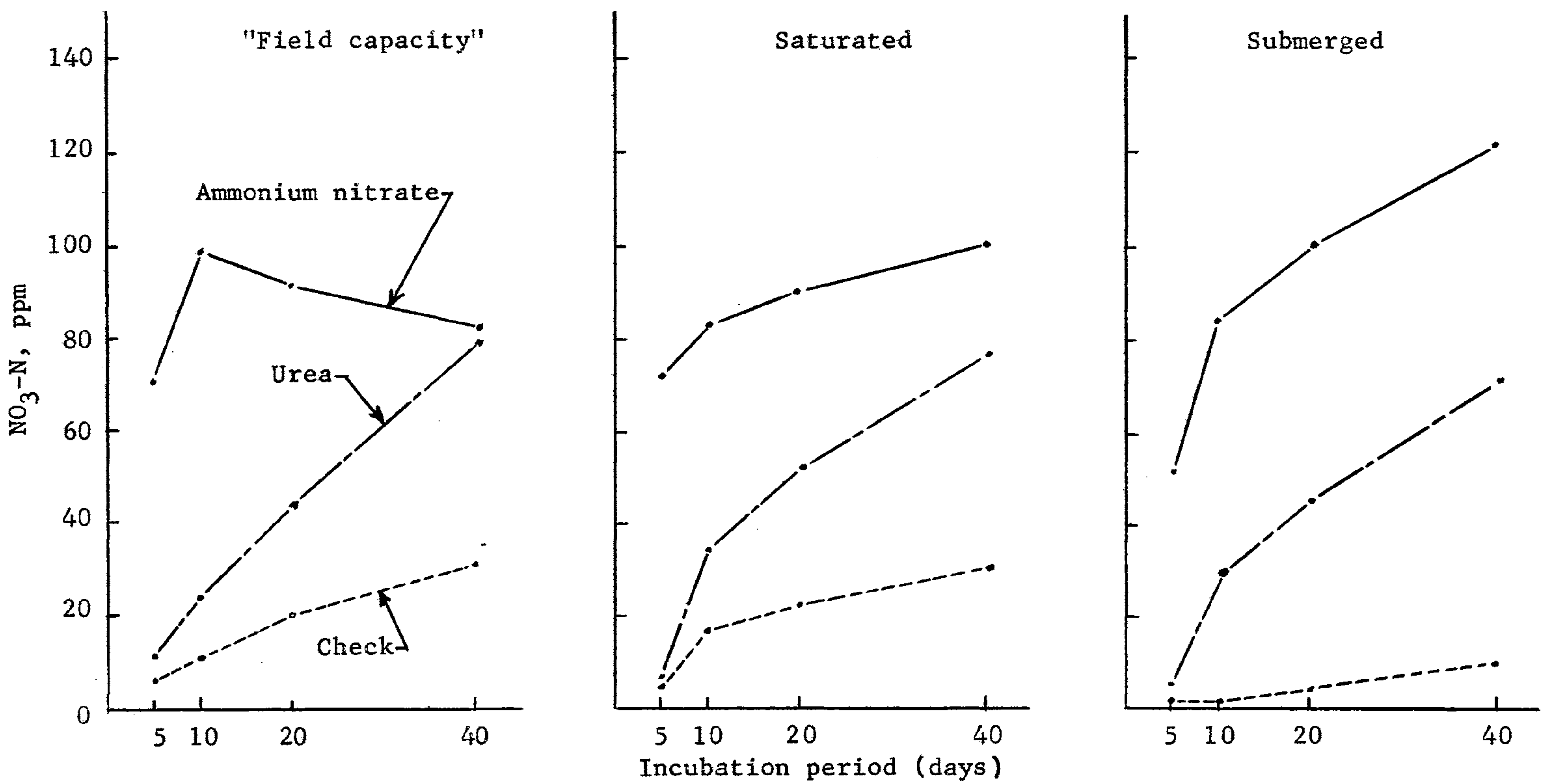


Figure 20. The Amount of Water-soluble NO_3-N in Taloka Silt Loam at Various Incubation Periods and Moisture Levels. The Soil Was Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

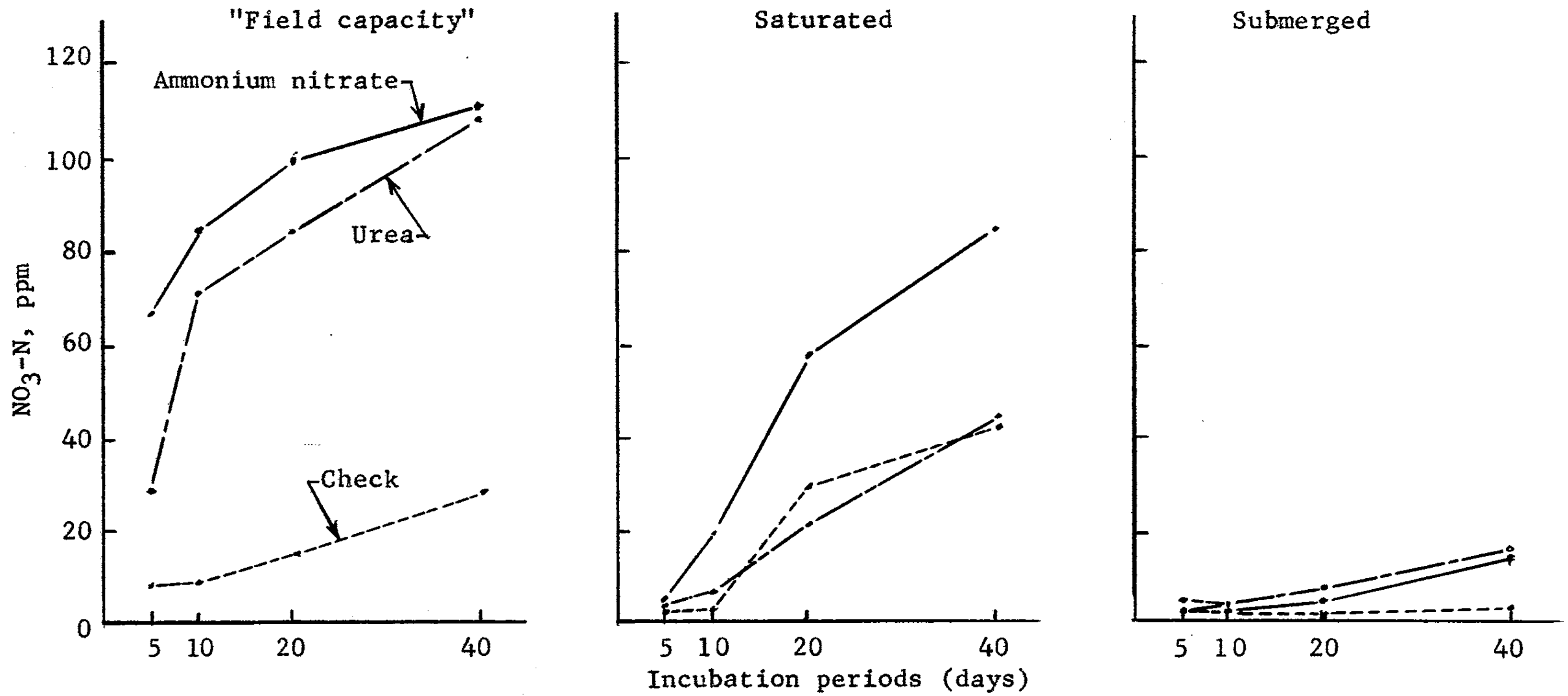


Figure 21. The Amount of Water-soluble NO_3-N in Brewer Clay Loam at Various Incubation Periods and Moisture Levels. The Soil Was Treated with 100 lb/A N from Urea and Ammonium Nitrate. Values are Means of Three Replications

TABLE XXXVII

THE ANALYSIS OF VARIANCE, MEAN VALUES AND LSR OF NO_3-N FROM UREA AND AMMONIUM NITRATE IN TALOKA SILT LOAM AND BREWER CLAY LOAM AT VARIOUS INCUBATION PERIODS WITH 100 lb/A N, THE MEAN VALUES ARE SHOWN IN FIGURES 20 AND 21

Source of variation	df	Mean square
Replications	2	62.9744
Soils (S)	1	16265.6258**
N sources (N)	2	53453.9508**
Moisture levels (M)	2	16540.0909**
Incubation periods (I)	3	15134.4599**
S x N	2	8630.7347**
S x M	2	12776.9557**
S x I	3	104.0370**
N x M	4	1963.6608**
N x I	6	1008.1101**
M x I	6	543.4343**
S x N x M	4	3846.7950**
S x N x I	6	462.4817**
S x M x I	6	747.7937**
N x M x I	12	241.6552**
S x N x M x I	12	336.7544**
Error	142	24.5999

Mean NO_3-N

Soil	N source	Moisture level	Incubation period (days)			
			5	10	20	40
Taloka s. l.	Check	FC	7.1	11.6	21.2	31.5
		Sat.	5.4	17.5	22.4	31.2
		Sub.	1.9	1.9	3.8	9.7
	Urea	FC	12.3	24.6	44.7	83.1
		Sat.	6.1	35.3	53.1	77.3
		Sub.	5.8	35.3	53.1	77.3
	Am. nitrate	FC	72.3	100.6	93.1	83.7
		Sat.	73.1	84.0	90.8	101.4
		Sub.	62.5	84.6	101.1	122.5

Continued next page

TABLE XXXVII Continued:

Soil	N source	Moisture level	Incubation periods (days) 5	10	20	40
Brewer c. l.	Check	FC	9.2	9.6	15.2	29.4
		Sat.	1.3	2.7	28.9	43.0
		Sub.	1.7	0.9	1.7	2.9
	Urea	FC	29.5	72.3	85.3	109.3
		Sat.	3.6	6.4	21.6	43.7
		Sub.	4.5	2.2	7.4	15.0
	Am. nitrate	FC	67.5	85.6	101.0	116.1
		Sat.	3.2	18.9	58.1	85.1
		Sub.	1.4	0.9	4.3	14.4

LSR values

α level	Number of pairs 2	3	4	5	6	7	8	9	10	11	12
5%	11.2	11.8	12.2	12.5	12.7	12.9	13.1	13.2	13.3	13.4	13.5
1%	14.8	15.4	15.8	16.1	16.4	16.6	16.7	16.9	17.0	17.2	17.3

**Significant at 1% level.

probably indicate that the denitrification process under submerged conditions of soils without any plant growing on it, is influenced by several factors. In this case, the suspected dominant factor causing the unexpected results was the slowing down of denitrification with increasing incubation due to lack of energy (C) source in the soil to sustain vigorous microbial reduction (and hence, denitrification) process. This writer, in a special laboratory study in Advanced Soil Soil Biology at Oklahoma State University, obtained results indicating that reducing conditions of a submerged Zaneis loam (reddish brown) soil as reflected by change in soil color from reddish brown to iron gray, was detectable only when 1 per cent sucrose solution was added to the submerged soil. Allison _et al_. (1960) also reported that denitrification due to reduction by microbes was enhanced considerably when 0.5 per cent glucose was added to the incubated soil.

In the Brewer clay loam, the amount of NO_3-N released was drastically decreased as the amount of water in the soil increased. In this soil urea showed the same trend and amount as the check at saturation while at submergence, the amount was the same for check and the two N carriers. It may be that in the Brewer soil denitrification under submerged conditions was much more vigorous than in the Taloka soil so that a much lower NO_3-N was found in the Brewer than in the Taloka.

N Distribution in the Profile

The movement of N in the soil profile was studied in the field and in undisturbed soil cores. The field study was done on Port loam with bermudagrass fertilized as high as 400 lb/A N from urea and ammonium nitrate. The core study was on five soils: Port loam, Vanoss silt loam, Taloka silt loam, Tipton clay, and Hollister silty clay loam.

Field Plots

The results of the field study on N distribution in the soil profile of Port loam are reported in Figure 22, and in Table XXXVIII for "total" N. In the urea treatments the 200- and 400-lb/A N rates significantly increased "total" N at the first foot depth. Below the first foot depth increment, no significant increases were noted as a consequence of N applications. In the ammonium nitrate treatments the 200- and 400-lb/A N rates also significantly increased "total" N at the first foot depth. At the 28- to 32-inch depth increment the 400-lb/A N rate caused a significant increased in "total" N while the 200-lb/A

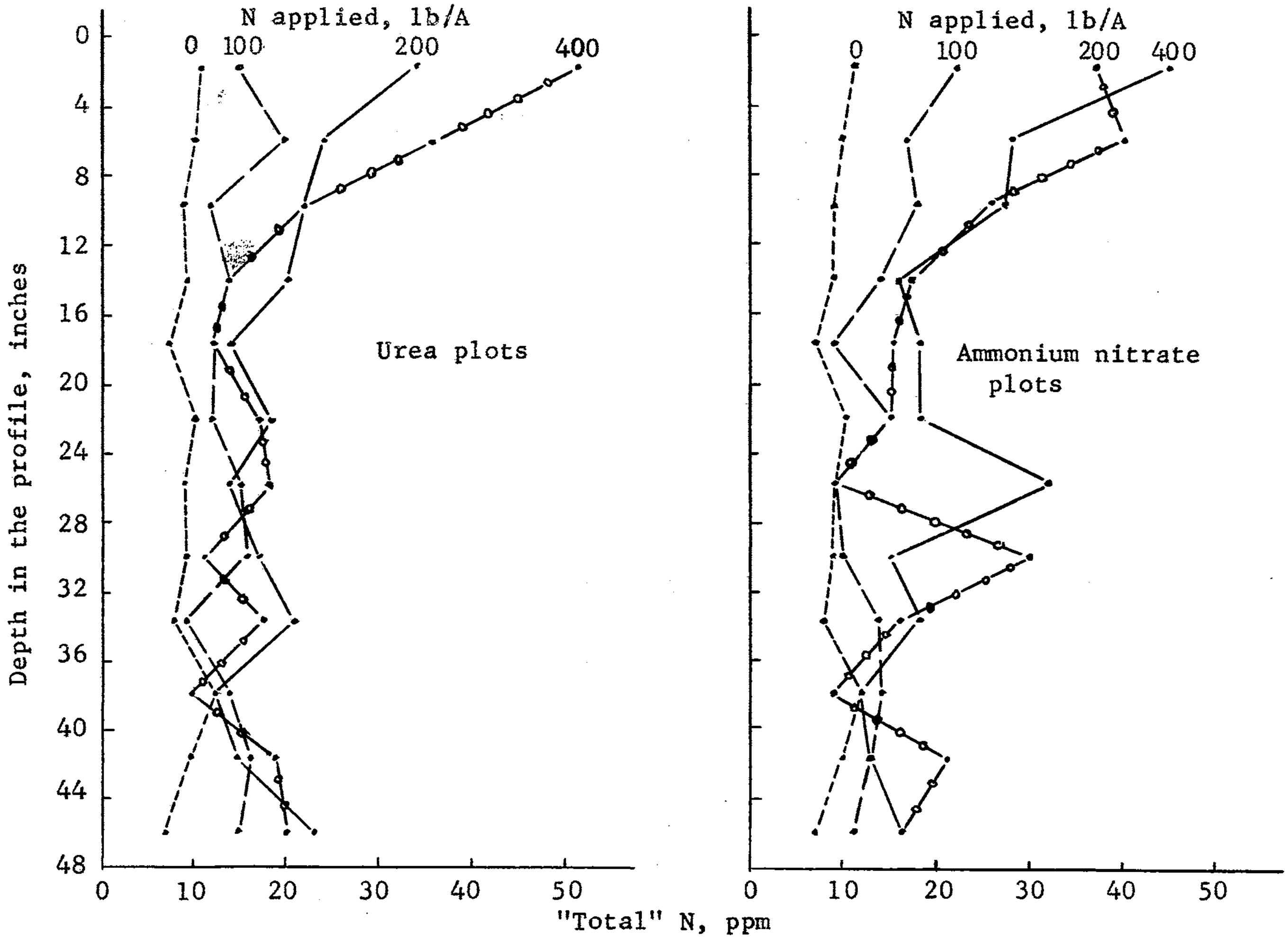


Figure 22. The Distribution of "Total" N in the Profile of Port Loam with Bermudagrass Fertilized with Varying Amounts of Urea and Ammonium Nitrate Three Months Before the Profile Samples Were Taken. Values are Means of Three Replications

TABLE XXXVIII

THE MEAN "TOTAL" N, ANALYSIS OF VARIANCE AND LSR IN THE PROFILE OF PORT LOAM WITH BERMUDAGRASS FERTILIZED WITH VARYING RATES OF UREA AND AMMONIUM NITRATE THREE MONTHS BEFORE SAMPLING. THE MEAN VALUES ARE SHOWN IN FIGURE 22

Nitrogen Source	N rate (lb/A)	Depth increment in the profile, in. 0-4 / 25-28	5-8 / 29-32	9-12 / 33-36	13-16 / 37-40	17-20 / 41-44	21-24 / 45-48
Urea	0	11.1	9.5	8.7	8.7	6.9	9.7
		8.8	8.6	7.5	11.8	10.3	7.2
	100	15.3	20.3	11.9	13.5	12.5	12.5
		15.1	15.5	9.1	13.2	15.5	14.7
	200	34.5	24.0	21.6	19.7	13.7	18.2
		14.2	17.2	20.9	12.3	14.7	22.8
	400	51.1	35.6	22.4	14.3	12.0	17.2
		18.2	11.4	18.4	9.7	18.9	20.4
Am. nitrate	0	11.1	9.5	8.7	8.7	6.9	9.7
		8.8	8.6	7.5	11.8	10.3	7.2
	100	22.2	17.2	18.5	14.2	9.0	15.3
		9.2	10.2	13.6	14.3	12.6	11.0
	200	44.9	28.2	26.7	15.5	17.6	17.8
		32.5	15.4	18.4	11.8	12.9	15.9
	400	36.8	39.5	26.3	17.3	15.3	14.8
		9.4	30.5	16.2	8.9	21.0	15.9

Analysis of variance

Source of variation	df	Mean square
Replications	2	589.4981**
N sources (N)	1	30.7459
N rates (R)	3	2300.7676**
Depth in the profile (D)	11	567.7637**
N x R	3	22.3703
N x D	11	26.7339
R x D	33	140.2121**
N x R x D	33	58.9956**
Error	190	31.2281

LSR values

α level	Number of pairs 7	2 / 8	3 / 9	4 / 10	5 / 11	6 / 12
5%		12.5	13.2	13.6	13.9	14.2
	14.4	14.6	14.8	14.9	15.0	15.1
1%		16.4	17.1	17.6	17.9	18.2
	18.5	18.7	18.9	19.0	19.1	19.2

**Significant at 1% level.

N rate did the same at the depth of 24 to 28 inches. It should be mentioned at this point that during the profile sampling with a three-inch soil auger, the writer noted a "fragipan-like" soil structure at 30 to 36 inches depth which was dry. Probably water had not reached down the profile beyond this depth.

NH_4-N distribution. The results of this study are shown in Figure 23 and Table XXXIX. In the urea treatments, only the 400-lb/A N caused a significant increase in NH_4-N at the first 8 inches depth in the profile. At the 24- to 28-inch depth, the 400-lb/A N significantly increased NH_4-N while the 200-lb/A N rate did the same at the depth of 32 to 36 inches.

In the ammonium nitrate plots the 200- and 400-lb/A N rates also caused a significant increase in NH_4-N at the first 8 inches depth in the profile. At the 24- to 28-inch depth the 400-lb/A N rate increased significantly the NH_4-N. The same effect happened at the 24- to 28-inch and 32- to 36-inch depths with the 200-lb/A N rate.

The data suggest that NH_4-N did move down the profile three months after applying 200 and 400 lb/A N rates to bermudagrass, and this movement reached a depth of 32 to 36 inches down the profile.

NO_3-N distribution. The NO_3-N distribution in the profile of Port loam with bermudagrass is shown in Figure 24 and Table XL. In the urea plots 200 and 400 lb/A N rates significantly increased the NO_3-N at the first foot depth increment of the soil profile. At 32- to 36-inch depth 400 lb/A N substantially increased the NO_3-N.

In the ammonium nitrate plots all the rates of N above 0 increased significantly the NO_3-N at the first foot of the soil profile. At 24- to 28-inch depth 200 lb/A N significantly increased the NO_3-N while

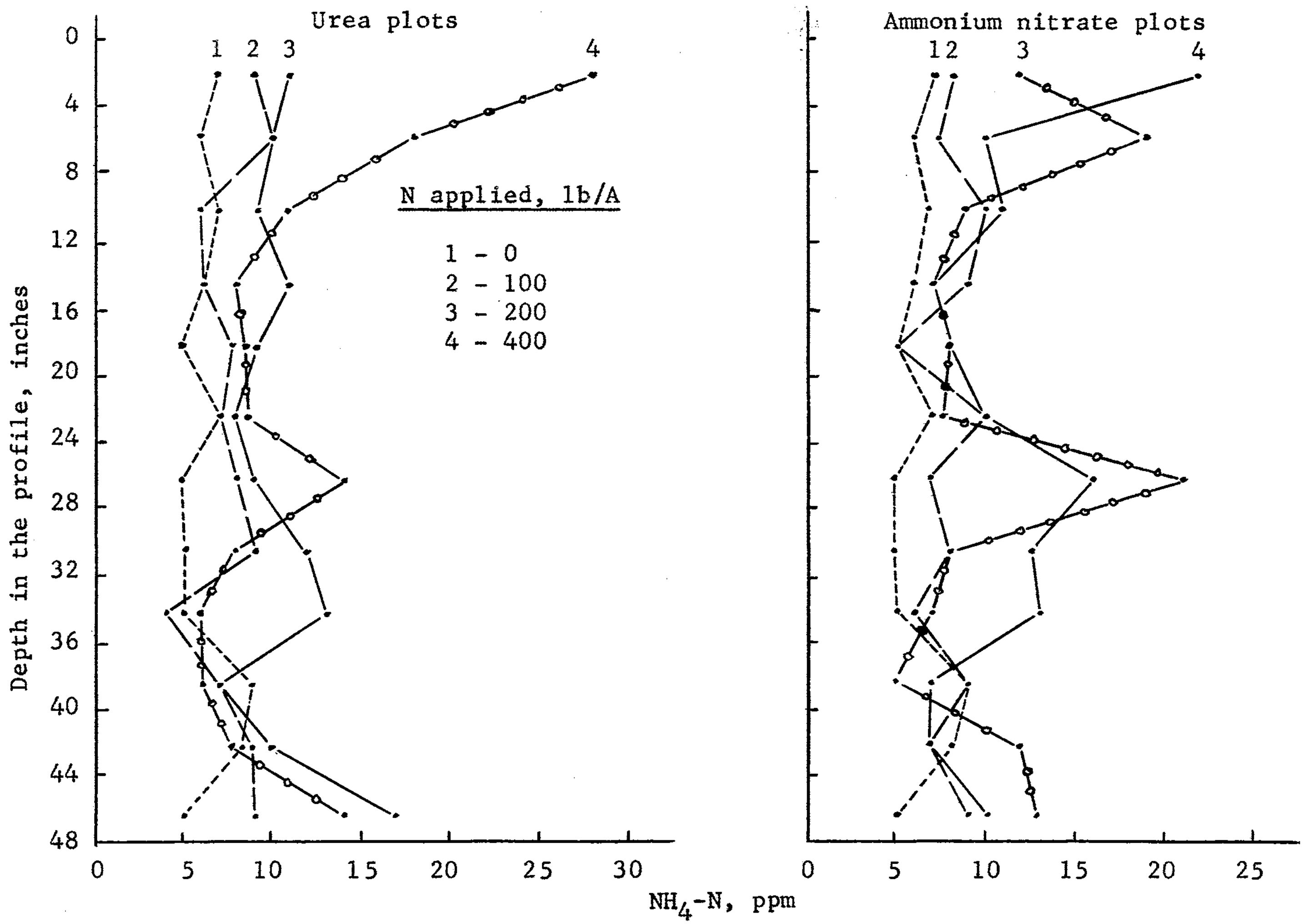


Figure 23. The NH_4-N Distribution in the Profile of Port Loam with Bermudagrass Fertilized with Varying Rates of Urea and Ammonium Nitrate Three Months before Taking the Profile Samples. Values are Means of Three Replications

TABLE XXXIX

THE MEAN NH_4-N, ANALYSIS OF VARIANCE AND LSR IN THE PROFILE OF PORT LOAM WITH BERMUDAGRASS FERTILIZED WITH VARYING RATES OF UREA AND AMMONIUM NITRATE THREE MONTHS BEFORE SAMPLING. THE MEAN VALUES ARE SHOWN IN FIGURE 23

Nitrogen source	N rate (lb/A)	Depth increment in the profile, in.					
		0-4 25-28	5-8 29-32	9-12 33-36	13-16 37-40	17-20 41-44	21-24 45-48
Urea	0	7.0	6.1	6.6	6.5	5.4	7.0
		5.3	6.1	5.2	9.4	8.4	5.4
	100	8.9	10.3	5.8	5.8	8.1	7.2
		7.6	8.9	4.1	6.8	8.8	8.8
	200	11.3	10.0	9.5	11.3	8.6	8.1
		8.8	7.6	6.0	9.2	6.9	9.4
	400	28.0	17.7	10.7	7.8	8.5	8.4
		13.5	12.5	12.9	6.9	6.7	9.9
Am. nitrate	0	7.0	6.1	6.6	6.5	5.4	7.0
		5.3	6.1	5.2	9.4	6.9	9.4
	100	8.2	7.5	9.6	8.9	5.3	10.2
		6.8	7.6	6.0	9.2	6.9	9.4
	200	22.0	10.4	10.7	6.8	7.6	9.7
		15.8	12.5	12.9	6.9	6.7	9.9
	400	11.6	18.9	9.2	6.8	7.7	7.4
		6.9	7.6	6.8	5.3	12.0	13.4

Analysis of variance

Source of variation	df	Mean square
Replications	2	83.5023**
N sources (N)	1	6.7528
N rates (R)	3	304.6963**
Depth in the profile (D)	11	72.0560**
N x R	3	23.3128**
N x D	11	4.7580
R x D	33	38.5970**
N x R x D	33	26.0034**
Error	190	7.2238

LSR values

α level	Number of pairs					
		2	3	4	5	6
	7	8	9	10	11	12
5%		6.1	6.4	6.6	6.8	6.9
	7.0	7.1	7.2	7.2	7.3	7.3
1%		8.0	8.3	8.5	8.7	8.8
	8.9	9.0	9.1	9.2	9.3	9.3

**Significant at 1% level.

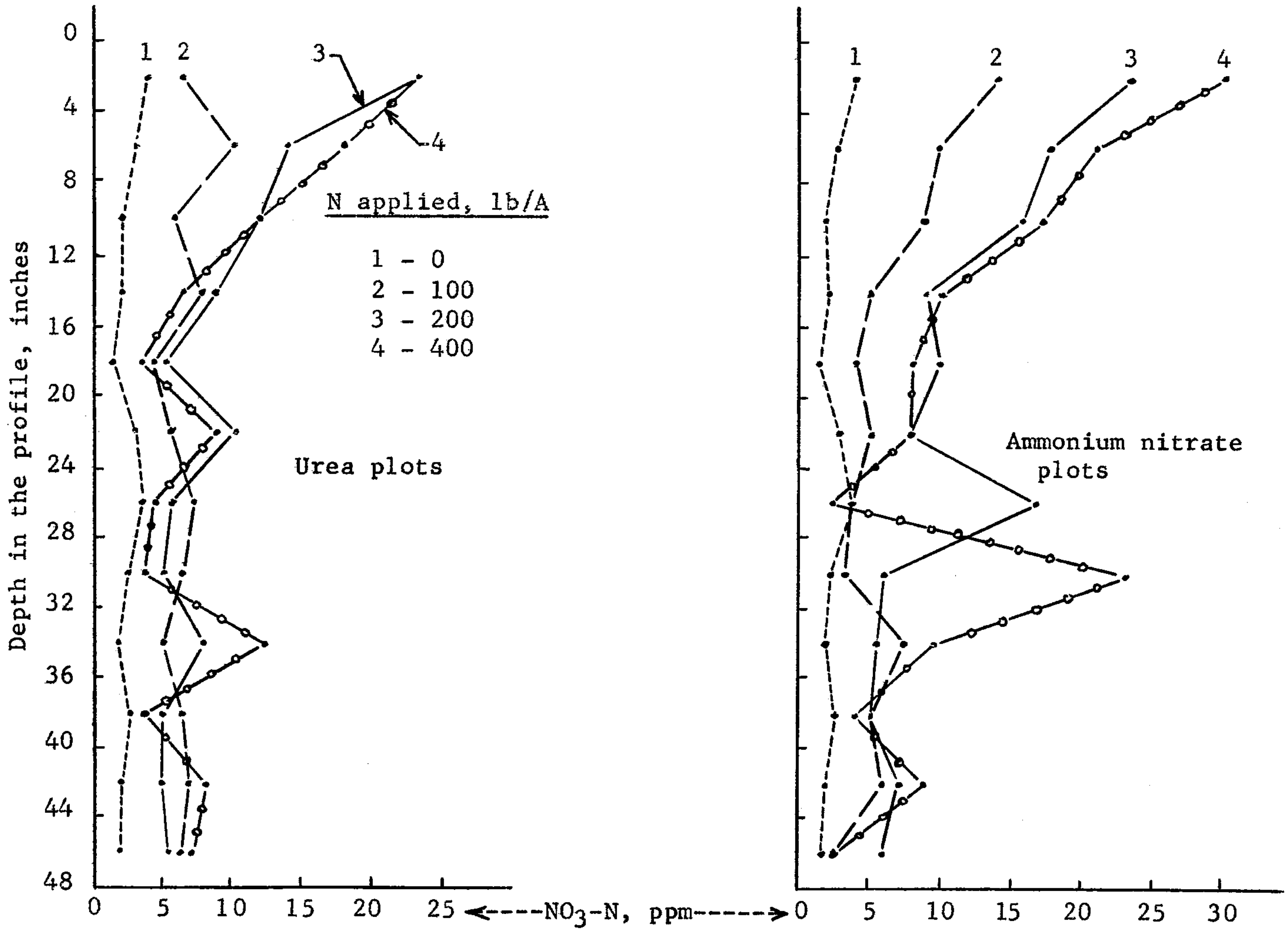


Figure 24. The NO_3-N Distribution in the Profile of Port Loam with Bermudagrass Fertilized with Varying Rates of Urea and Ammonium Nitrate Three Months before Taking the Profile Samples. Values are Means of Three Replications

TABLE XL

THE MEAN NO_3-N, ANALYSIS OF VARIANCE AND LSR IN THE PROFILE OF PORT LOAM WITH BERMUDAGRASS FERTILIZED WITH VARYING RATES OF UREA AND AMMONIUM NITRATE THREE MONTHS BEFORE SAMPLING. THE MEAN VALUES ARE SHOWN IN FIGURE 24

Nitrogen source	N rate (lb/A)	Depth in the profile, in. 0-4 / 25-28	5-8 / 29-32	9-12 / 33-36	13-16 / 37-40	17-20 / 41-44	21-24 / 45-48
Urea	0	4.1	3.4	2.2	2.2	1.5	2.7
		3.4	2.5	2.2	2.5	1.9	1.8
	100	6.4	9.9	6.1	7.7	4.4	5.3
		7.4	6.6	5.0	6.4	6.7	6.0
	200	23.2	14.1	12.1	8.5	5.1	10.1
		5.4	5.2	8.0	5.0	4.8	5.6
	400	23.1	17.9	11.7	6.5	3.5	8.8
		4.7	3.3	12.0	3.3	7.9	6.3
Am. nitrate	0	4.1	3.4	2.2	2.2	1.5	2.7
		3.4	2.5	2.2	2.5	1.9	1.8
	100	14.1	9.7	8.8	5.2	3.7	5.1
		2.4	2.6	7.6	5.2	5.7	1.6
	200	22.9	17.8	16.0	8.7	10.0	8.1
		16.7	6.2	5.5	4.9	6.6	6.2
	400	25.2	20.6	17.1	10.1	7.6	7.5
		2.5	22.8	9.4	3.7	9.0	2.5

Analysis of variance

Source of variation	df	Mean square
Replications	2	235.0127**
N sources (N)	1	66.3168**
N rates (R)	3	946.1313**
Depth in the profile (D)	11	281.9192**
N x R	3	37.3531**
N x D	11	18.5062*
R x D	33	56.7082**
N x R x D	33	25.8642**
Error	190	10.7160

LSR values

α level	Number of pairs / 7	2 / 8	3 / 9	4 / 10	5 / 11	6 / 12
5%		7.4	7.7	8.0	8.2	8.4
	8.5	8.6	8.7	8.8	8.9	9.0
1%		9.7	10.2	10.4	10.6	10.8
	11.0	11.1	11.2	11.3	11.4	11.5

*Significant at 5% level.
**Significant at 1% level.

400 lb/A of N did the same at 28 to 32 inches depth.

Looking at the profile distributions of NH_4- and NO_3-N in the field plots of Port loam (Figures 23 and 24) it appears that the NO_3-N which moved with the internal moisture percolating, was found at or near the wetting front while the NH_4-N was about four to eight inches behind the NO_3-N

Leaching Studies

Undisturbed soil cores from five soils in Oklahoma were leached with 100 lb/A N from urea or ammonium nitrate applied on the soil surface. The results are shown in Figures 25 to 28.

"Total" N distribution. The results of this study are shown in Figures 25 for urea and 25 for ammonium nitrate. In general, much of the urea N was retained at the top six inches of Port loam and Vanoss silt loam. Taloka silt loam, Hollister silty clay loam and Tipton clay did not retain much of the urea N anywhere in the profile. The same trend was true for the ammonium nitrate N except that more was retained in the top six inches by these two soils from the ammonium nitrate than from urea. In the urea treatment, Vanoss silt loam tended to increase the "total" N at 12- to 18- and 33- to 36-inch depths. In the ammonium nitrate treatment Port loam tended to increase "total" N at 30- to 33-inch depth. The hollister silty clay loam did the same at the depth of 27 to 30 inches.

NH_4-N distribution. The NH_4-N distribution patterns of the five soils are shown in Figure 27. In the urea treatment Vanoss silt loam again tended to increase NH_4-N at the 12- to 15- and 33- to 36-inch depths while Tipton clay tended to increase it at the depth of 42 to 45 inches. In the ammonium nitrate treatment Port loam again tended to

Urea treatment

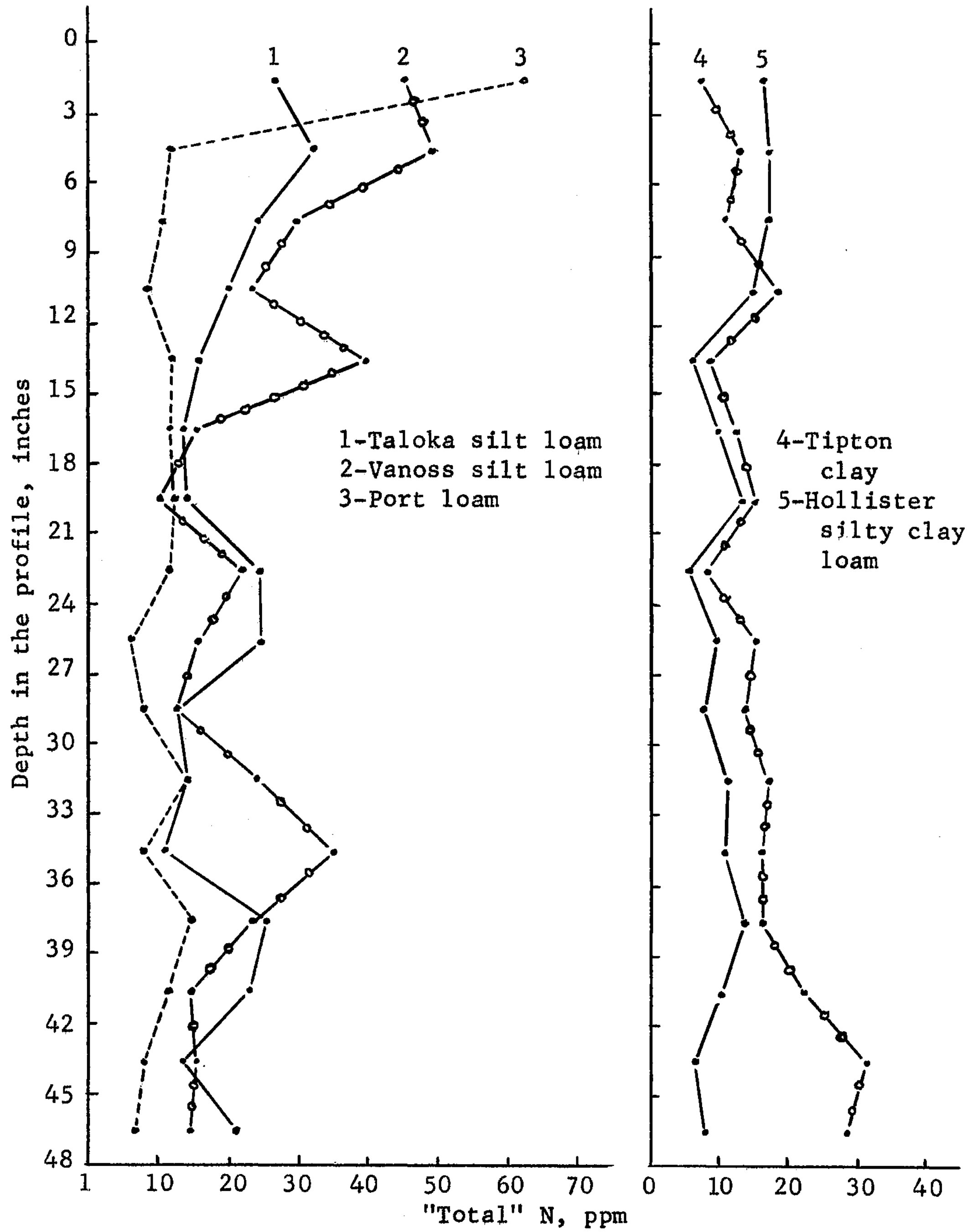


Figure 25. The Distribution of "Total" N in the Profile of Five Soils with Undisturbed Cores Leached with 100 ppm N from Urea. Values are from Single Observations for Each Profile

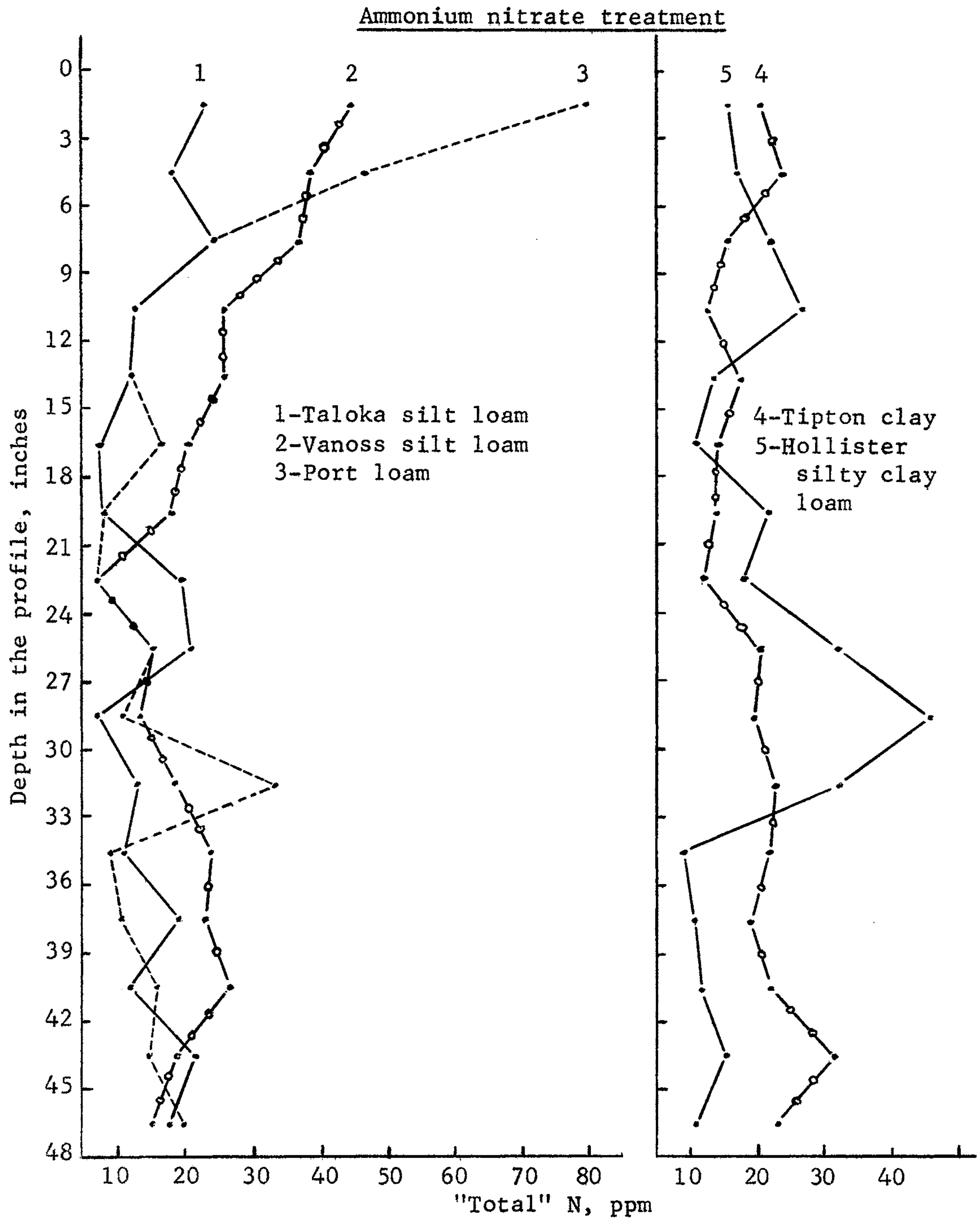


Figure 26. The Distribution of "Total" N in the Profile of Five Soils with Undisturbed Cores Leached with 100 ppm N from Ammonium Nitrate. Values are from Single Observations for each Profile

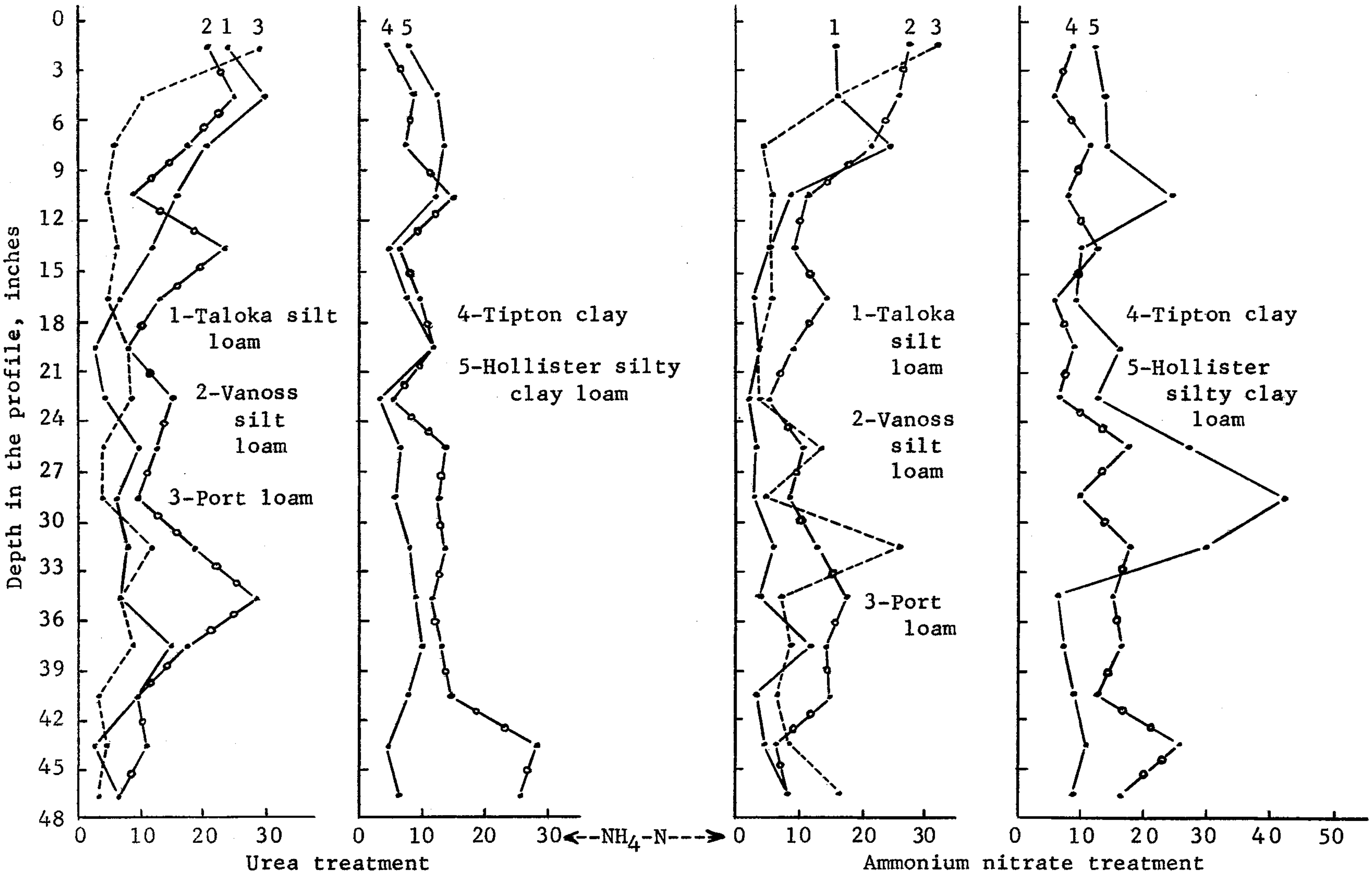


Figure 27. The Distribution of NH_4-N in the Profile of Five Soils with Undisturbed Cores Leached with 100 ppm N from Urea and Ammonium Nitrate. Values are from Single Observations for each Profile

increase NH_4-N at 30- to 33-inch depth.

<u>NO_3-N distribution</u>. The profile distributions of NO_3-N in the five soils are shown in Figure 28. In the urea treatment much of the NO_3-N in the Port loam and Vanoss silt loam was retained at the top three inches of soil. Taloka silt loam did not retain much NO_3-N at the surface layer but tended to increase NO_3-N at 21- to 24-inch depth. The Tipton clay and Hollister silty clay loam had uniformly low NO_3-N throughout the profile.

In the ammonium nitrate treatment Port loam retained much of the NO_3-N at the top nine inches of soil. Taloka silt loam again tended to increase NO_3-N at the 21- to 27-inch depth, while the Hollister silty clay loam tended to retain some NO_3-N at the top six inches.

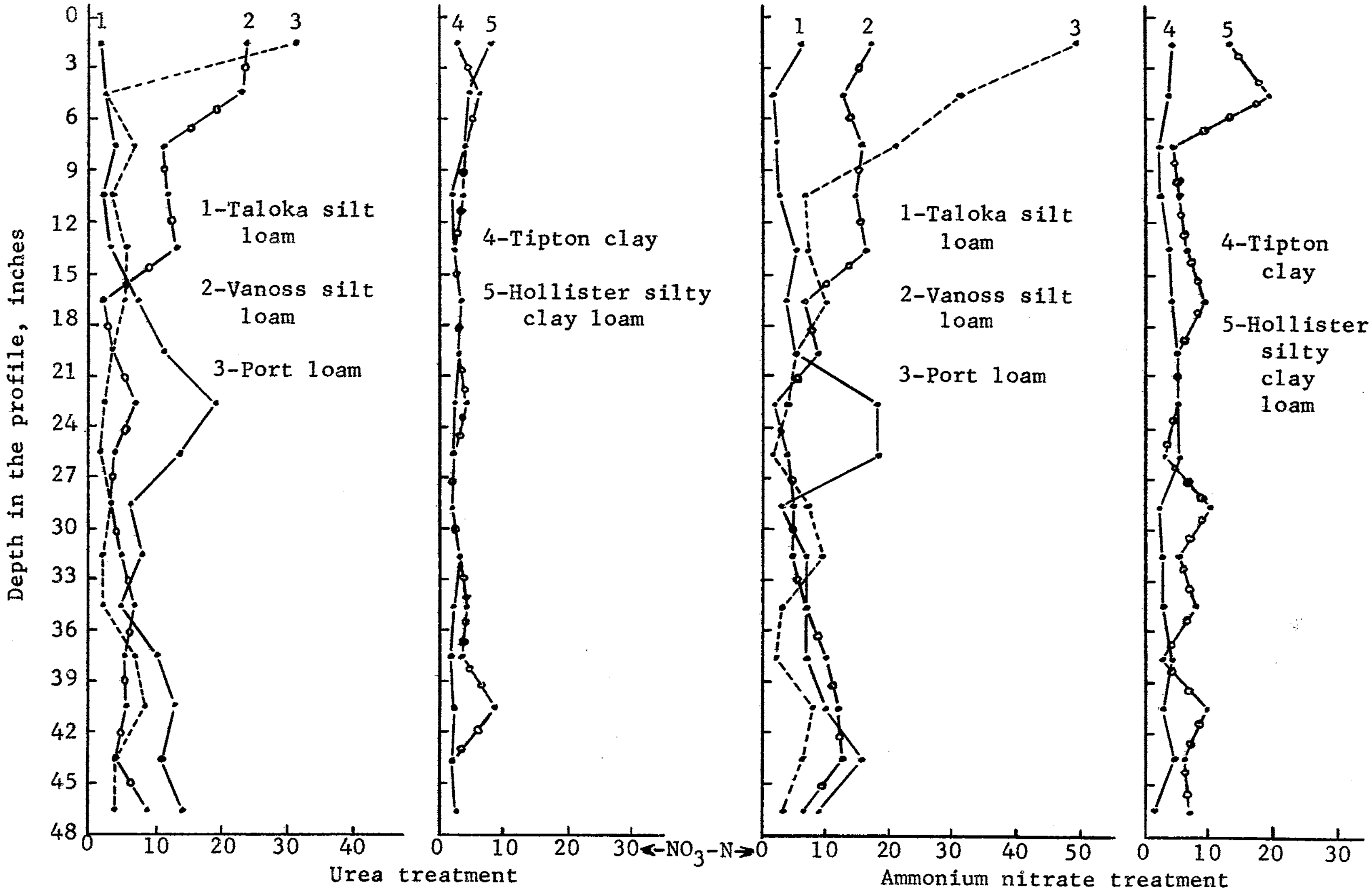


Figure 28. The Distribution of NO_3-N in the Profile of Five Soils with Undisturbed Cores Leached with 100 ppm N from Urea and Ammonium Nitrate. Values are from Single Observations for each Profile

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary and Conclusions

Field Experiments

In general the yield responses by grain and forage sorghums, bermudagrass and cotton to N applications were similar for urea and ammonium nitrate. Thus, it was found that urea was as good as ammonium nitrate in the field trials of the foregoing crops.

In greenhouse studies, urea was also found to be as effective as ammonium nitrate for sudangrass and Sudax. However, for paddy rice under continuous submergence (using IR 8 variety as indicator) urea was found superior to ammonium nitrate especially at the later stages of growth of the rice plant. The cause for this was attributed to denitrification of the NO_3-N from ammonium nitrate.

Redox potential measurement was made on continuously submerged Taloka silt loam soil with IR 8 rice growing on it and fertilized with 100 lb/A of N from urea and ammonium nitrate. The results showed that the urea-treated soil attained maximum reducing conditions more rapidly than the soil receiving ammonium nitrate. However, at 16 weeks after the rice seedlings were transplanted, more or less maximum reducing conditions were attained in the check as well as N-treated soils at the top 10 cm.

N release from urea and ammonium nitrate was studied by incubating Taloka silt loam and Brewer clay loam soils with 100 ppm N from both N carriers up to 40 days, at "field capacity," saturation and submergence. For both soils NH_4-N decreased drastically from 5 to 20 days of incubation whereas NO_3-N increased from 5 to 40 days of incubation, regardless of N source and moisture treatments. It was evident that nitrification was going on even at submergence, especially in the Taloka silt loam, up to 40 days of incubation.

The study on the movement of NH_4- and NO_3-N in the soil profile of Port loam with bermudagrass showed that three months after the applications of 200 and 400 lb/A N from urea and ammonium nitrate, a considerable amount of these forms of N moved down the profile to as deep as 32 inches. The NO_3-N moved with the percolating water at or near the wetting front whereas NH_4-N was four to eight inches behind.

Recommendations for Further Studies

1. For redox potential measurement, leave the electrodes stationary at various depths until the experiment is over. Inserting the electrodes at various depths every time redox potential measurement is made is not only tedious but liable to alter the redox potential at the depth of measurement. If the electrodes are left stationary, they should be rotated around first, by slightly pressing it against the soil, before making the measurements.
2. For denitrification studies, analyze the volatilized nitrogenous gas at "field capacity," saturation, and submerged conditions of loam, clay loam and clay soils to

determine what forms of gaseous N are volatilized under these conditions.

3. For leaching undisturbed clayey soil cores that have been air dried, either of the following is recommended to hasten percolation and prevent denitrification: (a) re-moisten the cores and let them equilibrate to about "field capacity" before leaching, or (b) put pressure on top of the water-head. The former requires less elaborate equipment than the latter.
4. Field-testing of urea and ammonium nitrate on paddy rice to confirm (or disprove) their effects obtained in the greenhouse.

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VITA[3]

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