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NITRIFICATION IN PREPLANT N-P FERTILIZER
BANDS AND PH EFFECTS ON NITRIFICATION

by

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INTRODUCTION

Since 1975 research has been carried out in Kansas on increasing phosphorus fertilizer efficiency by applying phosphorus in the same band with nitrogen fertilizer (Leikam, 1980). This type of band application, termed dual knifed N-P application, has shown agronomic benefits when compared to other preplant methods of fertilizer application on winter wheat (Triticum aestivum L.). These benefits include greater yield and phosphorus content in the grain.

Past studies in Kansas with different N sources in dual knifed N-P studies have shown that nitrogen fertilizers with ammoniacol nitrogen tended to give greater benefits than fertilizer with nitrate nitrogen in some cases and not in others. When analyzing these results the process of nitrification in these dual knifed bands was implicated by the researchers as a possible factor affecting the degree of fertilizer response.

To better understand the effect of nitrification on dual knifed N-P applications two studies were conducted in 1980 on winter wheat. The first study tried to change the rate and time of nitrification by changing the fertilizer application date and by using nitrification inhibitors. The second study was an N-rate study which was conducted with the thought that higher ammoniacol nitrogen concentrations might retard nitrification due to a higher pH in the application zone.

In conjunction with the field studies several laboratory studies were conducted on nitrification with pH and soil buffering capacity. The studies were designed to simulate anhydrous ammonia band conditions on several different soils.

LITERATURE REVIEW

Field Studies

The effect of added nitrogen on uptake of soil and fertilizer phosphorus has been known for a long time (Chapman, 1936). In the field when nitrogen is placed with phosphorus there is better efficiency of fertilizer phosphorus. Olsen and Dreier (1956) have found that fertilizer nitrogen stimulates plant use of phosphorus over a wide range of soil conditions. Lorenz and Johnson (1934) have shown that ammonium salts which are initially acid when added to water effectively released native soil phosphate.

Much research has been done to find the best method of placement to achieve the beneficial effects of added nitrogen on phosphorus efficiency. The best results were obtained in the field when both nitrogen and phosphorus fertilizers were banded (Werkhoven and Miller, 1960) and when those bands were placed together (Miller and Ohlrogge, 1958; Robertson et al., 1950; Grunes et al., 1958). Engelstad and Allen (1971) concluded that nitrogen placement is important only when phosphorus is banded. Miller and Ohlrogge (1958) found that nitrogen banded apart from phosphorus had an effect on phosphorus uptake only at low soil phosphorus levels.

Grunes et al. (1958) found, in a growth chamber experiment, that placement of ammonium sulfate gave the best results on phosphorus uptake when it was banded with the phosphorus, but sodium nitrate showed no difference whether banded with the phosphorus or on the other side of the plant roots. Also on fertilizer placement, Werkhoven and Miller (1960)

found that nitrogen and phosphorus banded together gave the same results whether banded shallow or deep. In this greenhouse study the shallow depth was 0-2 inches and the deep depth was 3-5 inches.

It was suggested in early research that the development of root mass in the fertilizer zone was the cause of increased phosphorus efficiency (Miller and Ohlrogge, 1958). Duncan and Ohlrogge (1959) showed that nitrogen and phosphorus placed together stimulated root growth more than if either nutrient was placed alone. They also showed that the greater growth was due to rapid development and branching of the smaller roots. This increase in root growth is thought to increase the feeding power of plants for phosphorus in the soil (Miller and Vij, 1962; Duncan and Ohlrogge, 1958; Engelstad and Allen, 1971). Some researchers though, do not think increased root growth is the reason that nitrogen increases phosphorus uptake (Bennett et al., 1962; Miller, 1965). Miller (1965) found in his research cases of increased phosphorus uptake before root growth was increased. Also, Engelstad and Allen (1971) suggest with early root growth it would be possible to get the added nitrogen effects at high soil phosphorus values, but that this effect would not last as the root system increased.

Many researchers have noticed a difference between forms of nitrogen on giving beneficial phosphorus fertilizer efficiency (Blair et al., 1970; Engelstad and Allen, 1971; Olsen and Dreier, 1956; Leikam, 1980). They have noticed that ammonium was better than nitrate in giving an increase in phosphorus uptake. One reason suggested for this difference is a reduced pH in the fertilizer zone due to acidity produced by nitrification or to acidity produced by an initially acid nitrogen fertilizer. Chapman

(1936) had shown that large decreases in soil pH increased phosphate availability. This increased availability is due to an increase in the $\text{H}_2\text{PO}_4^-/\text{HPO}_4^{2-}$ ratio at low pH (Miller et al., 1970) and by ion pairing with acidic ammonium salts (Olson and Dreier, 1956). Nitrates gave the same response as ammonium when soil pH was already low (Couldin and Sample, 1958) or when soil pH was lowered by sulfur acidification from pH levels where nitrates were not as effective as ammonium (Lorenz and Johnson, 1934). Riley and Barber (1971) suggested that the root surface pH is more important than the fertilizer zone pH. They found, using soil in pots, that the phosphorus content of a plant was closely correlated to the rhizocylinder pH but not to the bulk soil pH. The rhizocylinder pH can be lowered by absorption of ammonium (Soon and Miller, 1977). Miller et al. (1970) suggested that a lowered rhizocylinder pH was responsible for the prevention of phosphorus precipitation at the root surfaces in the presence of ammonium sulfate. Finally, Blair et al. (1971) found that a soil pH of 4.2 there was no root surface phosphorus accumulation and also no added ammonium effect on phosphorus uptake whereas at higher pH's there was an added ammonium effect.

Some researchers, though, suggest that acid formation and phosphorus solubility are not the only causes of added nitrogen effects on phosphorus efficiency. Several papers report increased phosphorus uptake without acid formation (Bennett et al., 1962) or increased phosphorus availability in the soil (Blanchard and Caldwell, 1966; Rennie and Soper, 1958). Also, Nielson et al. (1967) report greater phosphorus uptake when nitrification of ammonium is inhibited. Blair et al. (1970) have suggested

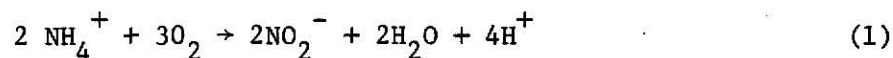
a cation-anion balance effect in root uptake of ammonium and phosphates. Leonce and Miller (1966) have suggested that the ammonium ion has a specific influence on the transfer of phosphates across the root symplast to the xylem, since nitrates caused a high accumulation of phosphorus in the roots but ammonium didn't.

Many researchers who haven't noticed a difference between forms of nitrogen have suggested that both ammonium and nitrates play a role in the uptake mechanisms of phosphorus (Olson and Dreier, 1956; Rennie and Soper, 1958; Soon and Miller, 1977). Cole et al. (1963) found that pretreating corn roots in solutions of nitrogen increased phosphorus uptake. The same increase in uptake was not obtained without pretreatment even when the phosphorus concentration was increased tenfold. Also using solution experiments, Thien and McFee (1970) found that nitrogen pretreatment increased both uptake and translocation of phosphorus. They also noticed that uptake and translocation were increased by different degrees and therefore suggested there were two separate transport systems with nitrogen requiring metabolites. In a later study Thien and McFee (1972) found that both systems were dependent on the nitrogen level in the pretreatment. At lower concentrations of nitrogen only uptake was stimulated. At higher concentrations only transport of phosphorus was stimulated.

From the research to date it appears that ammonium is superior to nitrate for increasing phosphorus efficiency due to their effect on soil conditions which help determine phosphate forms in the soil. However, both forms of nitrogen increase the plant's ability to take up and translocate phosphorus. In a field situation all factors discussed will play a role in increasing phosphorus efficiency.

Laboratory Studies

Nitrification in soils refers to the oxidation of ammonium to nitrates. This process is generally shown as the two step reaction given in equations (1) and (2).



As can be seen from these equations nitrification uses oxygen and produces acidity. Three general processes of nitrification have been identified in soils. These include photonitrification, heterotrophic nitrification, and autotrophic nitrification.

Photonitrification in soils by sunlight is usually not important (Waksman and Madhok, 1937). However, photonitrification has been shown to be important in tropical soils during summer when temperatures exceed the maximum for bacterial metabolism (Tandon and Dhar, 1934).

Heterotrophic catalyzed nitrification is the conversion of ammonium and other nitrogenous compounds to nitrites by heterotrophic bacteria, actinomycetes, and fungi. This process occurs mainly in anaerobic or other adverse conditions and is not considered the most important process for the production of nitrites in soils (Tisdale and Nelson, 1975).

The process of autotrophic nitrification is thought to be the main process of soil nitrification (Waksman and Madhok, 1937). This process of soil nitrification is catalyzed by enzymes produced by the two autotrophic bacteria species Nitrosomonas sp. and Nitrobacter sp. The former catalyzes equation (1) and the latter catalyzes equation (2). These bacteria are gram-negative, rod-shaped bacteria which are obligate aerobes. Nitrification by this process over time has a basic lag period,

a maximum rate period, and a decline period which are common to most bacterial catalized processes (Sabey et al., 1959). The maximum rate period follows Michaelis-Menten kinetics for enzymes (Ardakani et al., 1974). The reactions of nitrification were found to be first order kinetics for low concentrations of substrate (Misra et al., 1974) and zero order kinetics for high concentrations of substrate (Ardakani et al., 1974; Wong-Chong and Loehr, 1975).

Recently, it has been shown that soils do not act as a homogenous medium for nitrification. Molina et al. (1979) have concluded from their studies that "kinetics of ammonia oxidation in soil, for the nonsteady state situation represents the resultant average of pulses of activity from small isolated and asynchronous ammonium oxidizer clusters." They also noticed that "oxidation of ammonium around each cluster which harbors on the average a few hundred cells (a microcolony) is very rapid and the exponential model applies."

In past studies, soil organisms have given four general patterns of nitrification, which are given below (Morrill and Dawson, 1967).

- I. Rapid oxidation of ammonium to nitrite, which is accumulated over a long period of time before oxidation to nitrate.
- II. Ammonium and nitrate both rapidly oxidized.
- III. Ammonium slowly oxidized to nitrates with no nitrite detected.
- IV. Ammonium oxidation not detected.

The type of pattern for a given soil is determined by soil properties and bacterial concentrations and proliferation.

Of the above mentioned soil properties, one of the main factors affecting nitrification is soil temperature. The effect of temperature

on nitrification has been shown by many researchers (Chandra, 1962; Frederick, 1956; Meyers, 1975; Sabey and Bartholomew, 1956). The temperature range for nitrification is generally given as 0 to 40°C with an optimum range at 25° to 30°C. It has also been shown that a shift in temperature and the direction of shift had an effect on nitrification (Chandra, 1962). In soils it was found that regions of warmer climates had a higher optimum temperature for nitrification (Mahendrappa, 1966; Tandon and Dhar, 1934). In addition, nitrification has been shown to be faster in warmer climates and in soils that developed in warmer climates (Thiagalingam and Kanehiro, 1973). In one soil the maximum rate of nitrification was found to be independent of temperature from 9 to 35°C (Wong-Chong and Loehr, 1978), which suggested other limiting factors.

Another factor which also greatly affects nitrification is soil moisture (Miller and Johnson, 1964; Sabey, 1969; Reichman, et al., 1966). Nitrification is inhibited at both very high and very low moisture tensions and is proportional to water content from 15 to 0.2 bars of tension. Two researchers have also found a relationship between temperature and optimum moisture content (Kowalenko and Cameron, 1976). Kowalenko and Cameron (1976) report that optimum moisture contents for the activity of nitrifying organisms appeared to be dependent on temperature.

Aeration has also been reported to affect nitrification (Brand et al., 1964; Plummer, 1916). Aeration inhibits nitrification when the O₂ level is less than 0.5% (Misra et al., 1974). The rate of nitrification is also affected by initial population of nitrifying bacteria (Pang et al., 1974; Sabey, et al., 1959). The initial population of nitrifying

bacteria affects, besides rate, the pattern of nitrification (Morill and Dawson, 1967), the effect of temperature on nitrification (Frederick, 1956), and the temperature range of nitrification (Mahendrappa et al., 1966).

The rate of nitrification is also affected by the ammonium source (Anderson et al., 1970) and concentration (Tisdale and Nelson, 1975). Although rate was affected by source, one study showed no difference in final nitrate level (Caster et al., 1942).

High bulk density inhibits nitrification at high soil water contents where aeration can be a limiting factor (Hulpoi et al., 1970). Aggregate size was shown to affect the delay or lag period of nitrification (Brand et al., 1964). It was also observed that nitrification increased with degree of cultivation (Nyborg and Hoyt, 1978; Plhak and Vicherkova, 1970) but was not related to cropping practice in sod rotation and continuous sod (Anderson et al., 1970).

The effect of soil reaction is not well understood. In an early paper Lees and Onastel (1946) stated that "the rate of nitrification in a soil is a function of the base exchange capacity of the soil and that the process is confined to specific areas of the soil surface." They concluded from experimentation that nitrification diminished with amount of ammonia displaced from the soil surface by base exchange with calcium ions. But a later paper by Goldberg and Gainey (1953) concluded that availability of ammonium to bacteria may be related to quantity of unadsorbed ammonia and ammonium spontaneously released by ion exchange. In addition, they indicated that nitrification was not directly correlated to cation exchange capacity. Smith (1964), however, suggested that

cation exchange capacity indirectly affected nitrification by affecting pH and ammonium concentrations in the soil solution. An increase in pH can produce toxic levels of unionized ammonia in a soil solution. Later, Raju and Mukhopadyay (1974) showed that the amount of fixed ammonia which varies with clay type can affect the availability of ammonium for nitrification.

One of the least understood factors affecting nitrification is pH. Although there is much disagreement on pH ranges for nitrification the general values accepted for nitrifying bacteria growth in soils range from 3.5 to 4.5 for the minimum to 8.9 to 9.0 for the maximum (Waksman, 1952). For the processes of nitrification it is generally agreed that little bacterial nitrification occurs below pH 5 or above pH 8 and that oxidation of nitrite to nitrate is slowed above pH 7 (Meyers, 1974). The optimum pH is thought to be around neutrality (Wong-Chong and Loehr, 1978; Alexander, 1965), but there is considerable variation between areas and between isolates of the same area (Alexander, 1965). Some authors give much higher optimum pH values for laboratory cultures and Nitrobacter sp. were shown to adapt to a pH as high as 13.0 (Waksman, 1952). Meiklejohn (1954) has concluded that due to differences in pH response by different strains of nitrifying bacteria an optimum pH cannot be sharply defined for nitrification in general. What is known is that pH affects maximum rates of nitrification and the duration of delay periods (Dancer et al., 1973) and the activities of the initial nitrifying bacteria (Pang et al., 1974). The response curve over the pH range is often shown as a linear decrease from the optimum range until inhibition is reached (Meyers, 1974).

In acid soils, inhibition of Nitrosomonas sp. metabolism is thought to be the first cause of limiting nitrification (Dancer et al., 1973). Brur and Giddens (1968) had suggested that high concentrations of exchangeable aluminum ions restricted the metabolism of nitrifying bacteria in acid soils. But in a recent paper Nyborg and Hoyt (1978) found that although nitrification significantly decreased as pH was reduced, it did not decrease as base saturation decreased or as soluble iron, aluminum, or manganese ion concentration increased without a decrease in pH. Tyler and Broadbent (1960) found that nitrite concentrations inhibit the respiratory activity of all micro-organisms to a greater degree in acid soils and have suggested that this is the cause of nitrification inhibition at low pH values. Also, Weber and Gainey (1961) have reported that nitrification was more related to total organic nitrogen than hydrogen ion concentration in acid soils and that nitrification was very sensitive to inhibition by ammonium sulfate concentrations.

At high pH values inhibition is thought to affect Nitrobacter sp. sooner than Nitrosomonas sp. (Aleem et al., 1957; Smith, 1964; Stajanovic and Alexander, 1958). Aleem et al., (1957) have found that unionized ammonia is a selective inhibitor of Nitrobacter agile and only slightly inhibited Nitrosomonas europaea even at high concentrations. Unionized ammonia is implicated by the fact that degree of inhibition by ammonia increases with pH as does concentration of free ammonia (Warren, 1962; Wong-Chong and Loehr, 1978). Also as Warren (1962) states, "Since toxicity depends on the ammonia which enters the organism and thence the cell, it is of particular importance that cell membranes are relatively impermeable

to one form (ionized ammonia), whereas, the other (unionized ammonia) passes tissue barriers with ease."

Smith (1964) gives a value of 12.8 ppm free ammonia in soil solutions as toxic to Nitrobacter sp. But Dancer et al. (1973) state that some strains of Nitrobacter sp. are more sensitive to free ammonia than others. And Wong-Chong and Loehr (1975) give a range of 3.5 to 50 mg N l⁻¹ free ammonia in solution as being inhibitory to Nitrobacter sp.

As stated earlier, Smith (1964) has found a relationship between cation exchange capacity and toxic levels of free ammonia. He has found that decreasing the cation exchange capacity of a soil increases the soil solution pH and the concentration of ammonium in the soil solution when ammonia is added to the soil. These conditions lead to an increase in the concentration of free ammonia in solution.

Toxic conditions at high pH values have special importance in the use of anhydrous and aqua ammonia. Addition of these nitrogen sources raises the pH of the soil due to the following equilibrium where hydroxyl ions are produced.



For this reaction K equilibrium is 1.75×10^{-5} (Marion and Dutt, 1974). Fertilizer which contains unionized ammonia and is added to a water solution produces an initially alkaline soil solution. If ammonia containing fertilizers are used, unfavorable conditions may be produced initially in a soil before nitrification can proceed (Eno and Blue, 1954). The soil pH resulting from the use of these fertilizers depends on the soil's initial pH and on the soil's buffering capacity (Avnimeleck and Laher, 1977).

Finally, in regard to high pH, Molina et al. (1979) have found that inhibitory conditions of high alkalinity can be overcome when "under localized conditions of high ammonia supply, nitrite may chemically react and be metabolized under acid conditions when the [ammonium oxidizer] cluster has exhausted the buffering capacity of its surroundings at the end of its short period of activity."

Reviewing the more recent research would indicate that the relationship of nitrification to pH is dependent on other factors such as ammonium concentration, cation exchange capacity, and soil buffering capacity.

MATERIALS AND METHODS

Field Studies

Field studies were conducted in 1980 on winter wheat in north-eastern Kansas. Both studies were conducted at two sites, one in Jackson County and the other in Dickinson County (Table 1). One study had variables of timing of application of N and P, nitrogen source, method of application, and use of nitrification inhibitors and shall be referred to as the time of application study. The other study, called the N-rate study, had variables of nitrogen rates, method of application, and nitrogen sources. Treatment rates, methods of application, and fertilizer sources for the two studies are given in Tables (4-7).

The studies were conducted using a randomized complete block design with four replications. The individual plots were 9.1 m by 3.0 m with a 6.1 m alley between replication blocks. Fertilizer applications were made using a 46 cm knife spacing and a depth of application of approximately 15 cm. Preplant applications were made using a modified applicator (Fig. 1) with five knife shanks, each equipped with two discharge tubes (Fig. 2). The front tube was used to deliver anhydrous ammonia. The rear tube delivered liquid ammonia phosphate and urea-ammonium-nitrate solutions and was placed 3.8 cm behind the front tube to prevent freezing by the ammonia. Post-emergence applications were made with a different applicator (Fig. 3 & 4) equipped with five shanks preceded by rolling coulters and followed by compaction wheels. This applicator had a similar tube arrangement behind the shanks.

Table 1 Initial Soil Analysis for Field Studies

Location	Soil Type	Soil Depth (cm)	pH	Soil Test Measurements						
				NH ₄	NO ₃	I ⁻	K	Ca	Zn *	Fe *
Dave Adkins farm Jackson County	Pawnee clay loam	0-15	5.9	7.9	1.6	6	236	4705	0.54	73.8
	Aquic Argiudoll	15-30	6.4	3.5	0.3	2	172	6552	0.24	47.3
Jarod Hoover farm Dickinson County	Hastings silt loam	0-15	6.3	---	---	6	353	3612	0.88	44.5
	Udic Argiustoll									958

* DTPA extractable

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Figure 1 Preplant fertilizer applicator. A) Liquid solution container, B) anhydrous ammonia tank, C) solution pump on PTO ground drive, D) flow regulator for anhydrous ammonia, E) knife shank equipped with two tubes, F) boom with broadcast spray nozzles, and G) small anhydrous ammonia tank.

Figure 2 Close-up of preplant fertilizer applicator knife shank.

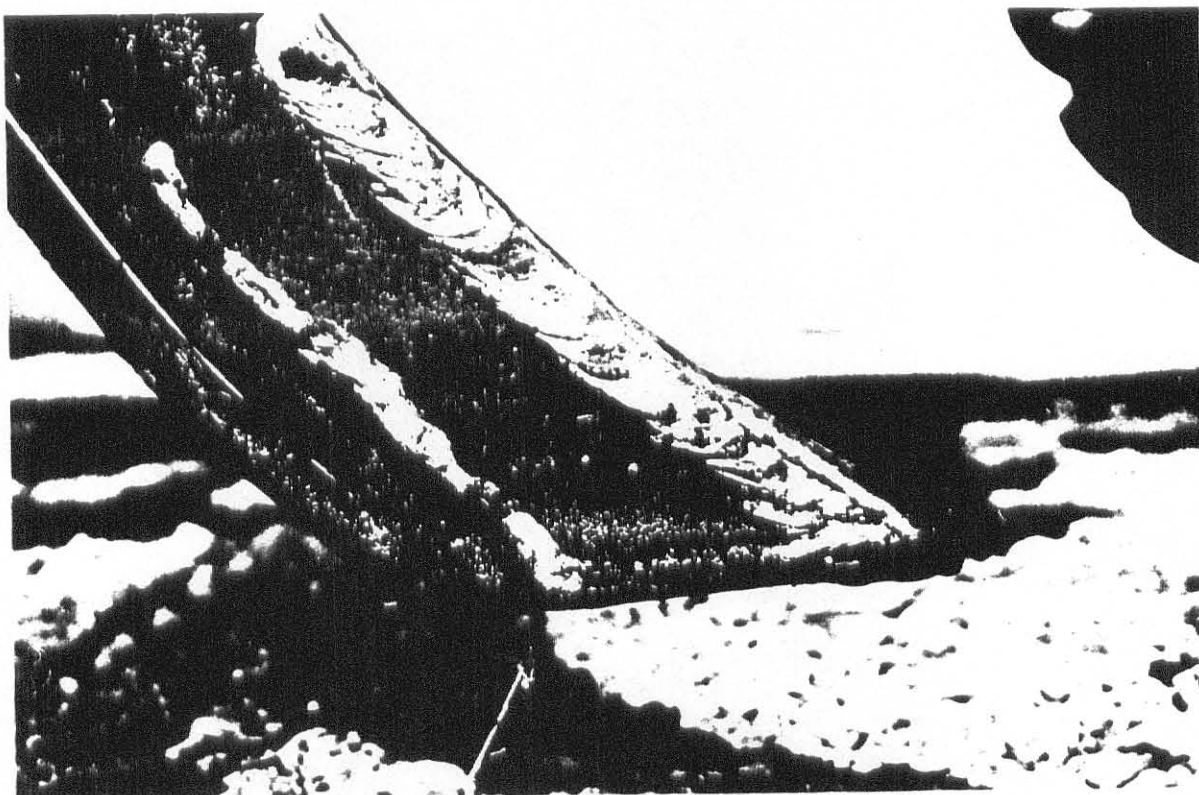
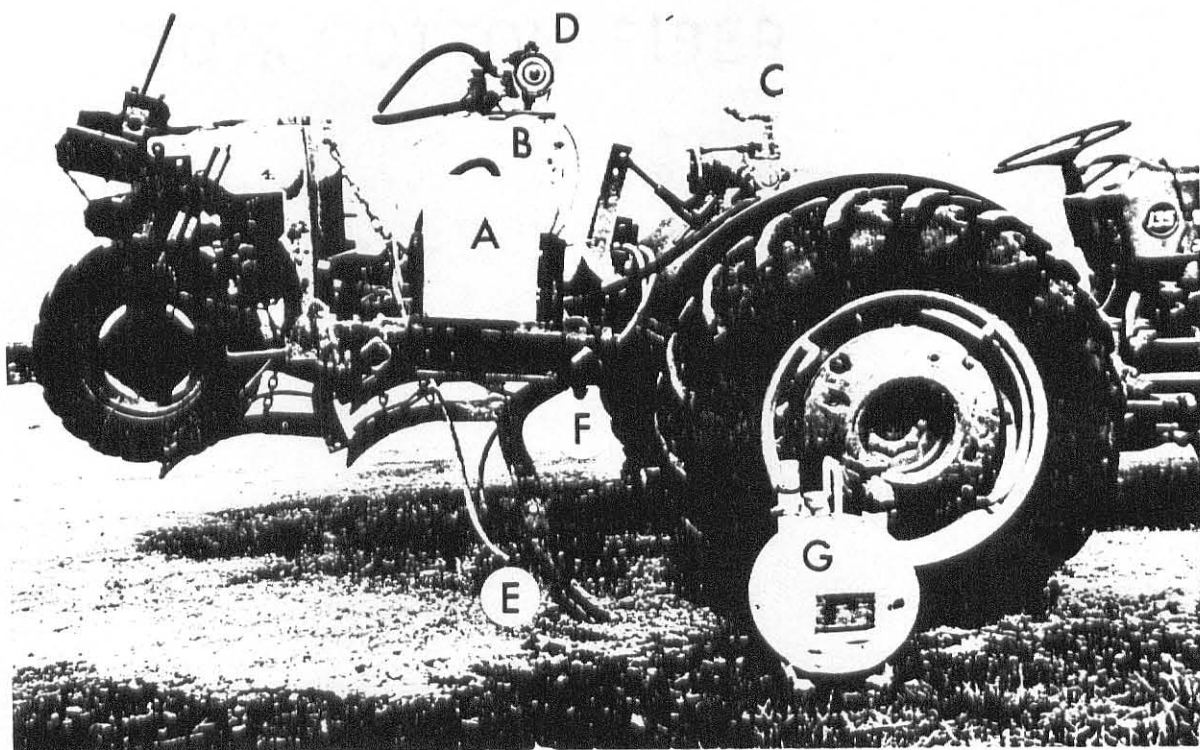
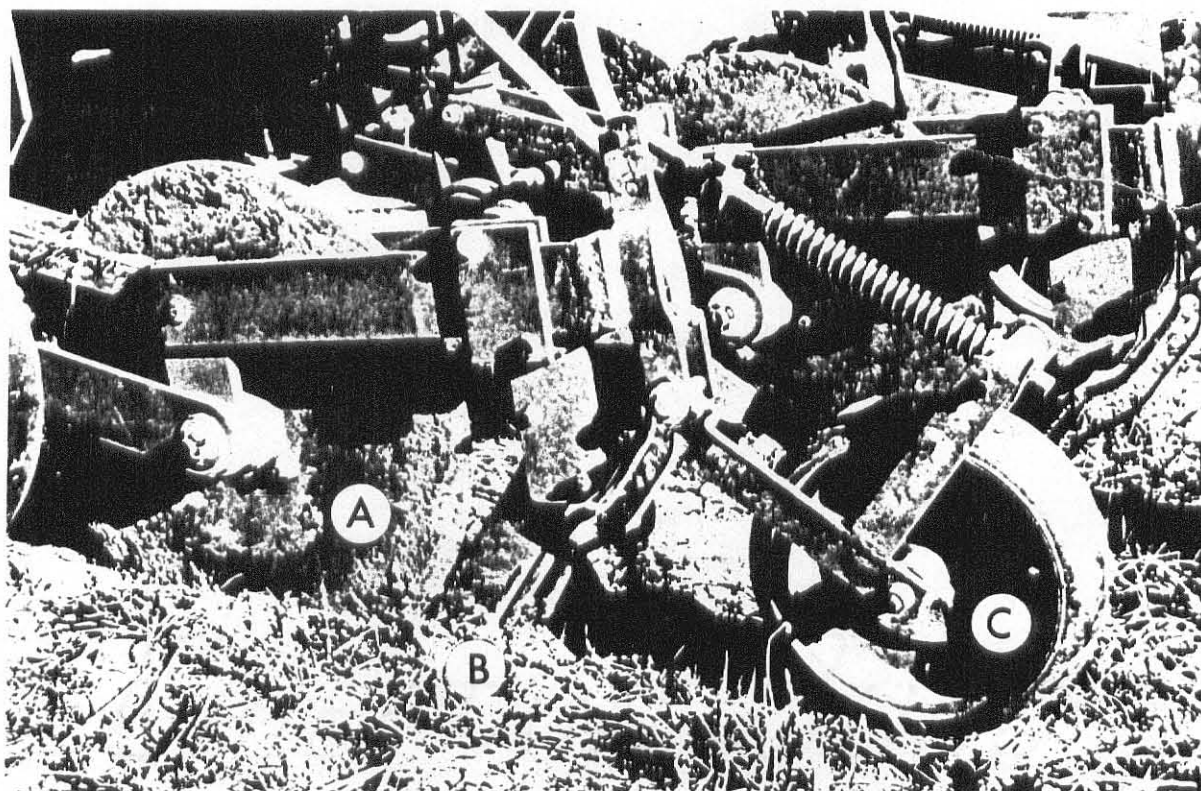
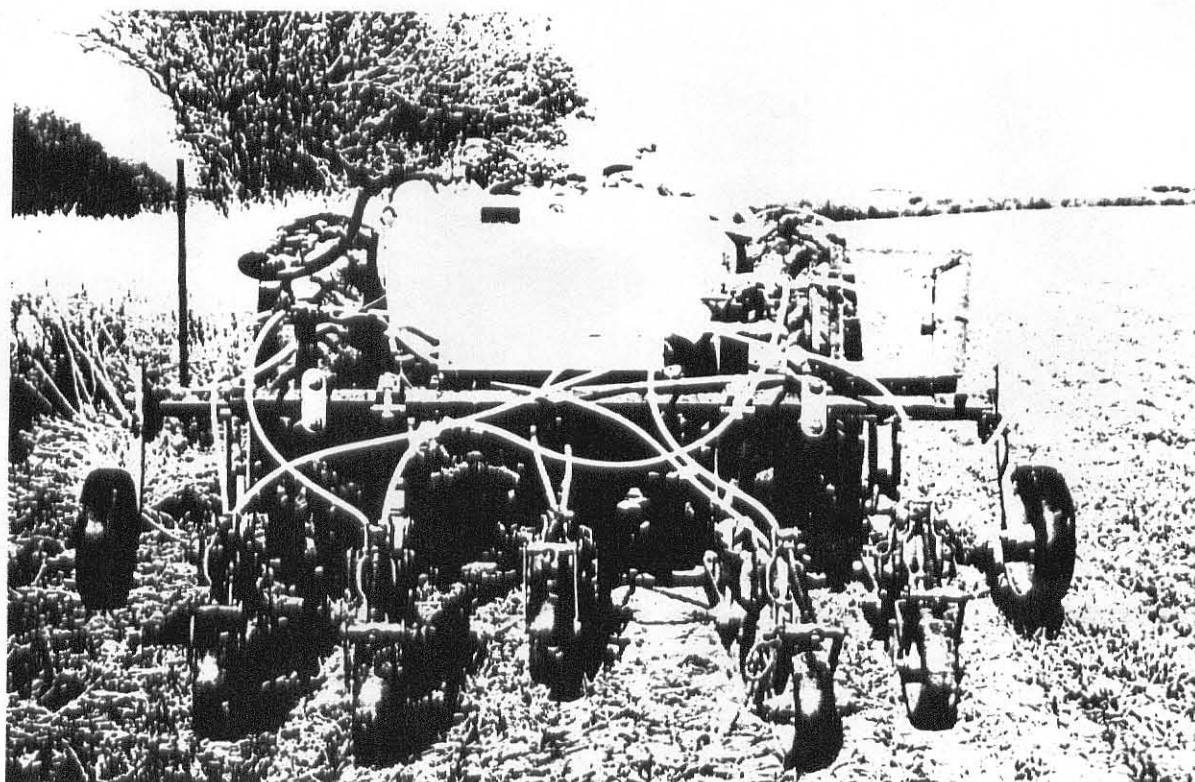


Figure 3 Post-emergence fertilizer applicator.

Figure 4 Post-emergence knife shank arrangement A) rolling coulter, B) knife shank with two application tubes and C) packing wheel.



Broadcast applications were applied with five V-jet nozzles mounted 46 cm apart on a boom which was positioned 46 cm above the soil surface. Uniform coverage of the soil was obtained by this method of application. The same boom was used on both applicators. Preplant broadcast applications were incorporated with subsequent light tillage performed by the cooperating farmers at each site. Knifed nitrogen-knifed phosphorus applications were made with one pass over the plots as were broadcast nitrogen-broadcast phosphorus applications. Combinations of broadcast-knifed applications required two passes.

Nitrogen sources used were anhydrous ammonia (NH_3) and urea-ammonium nitrate solution (UAN-28%). The phosphorus source was ammonium polyphosphate (APP, 10-34-0). When applied together the UAN and the APP were mixed in a single container. The time of application study also used two nitrification inhibitors. One was N-Serve 24 (Nitrapyrin) produced by Dow Chemical Corporation. This inhibitor was mixed directly with the anhydrous ammonia in a small 19 liter ammonia tank. The other inhibitor was Dwell (Etradiozole) which is produced by Olin Chemical Corporation. This inhibitor was mixed with the phosphorus solution with 10 ml of the wetting agent Wex added per liter of solution.

The Dickinson County site was planted with a 1.5 m Ontario drill with single disk openers spaced 17.8 cm apart. The site at Jackson County was planted by the cooperating farmer who also used a 17.8 cm row spacing. Both sites were planted using the wheat variety Newton with the rows parallel to the direction of the knifed fertilizer bands.

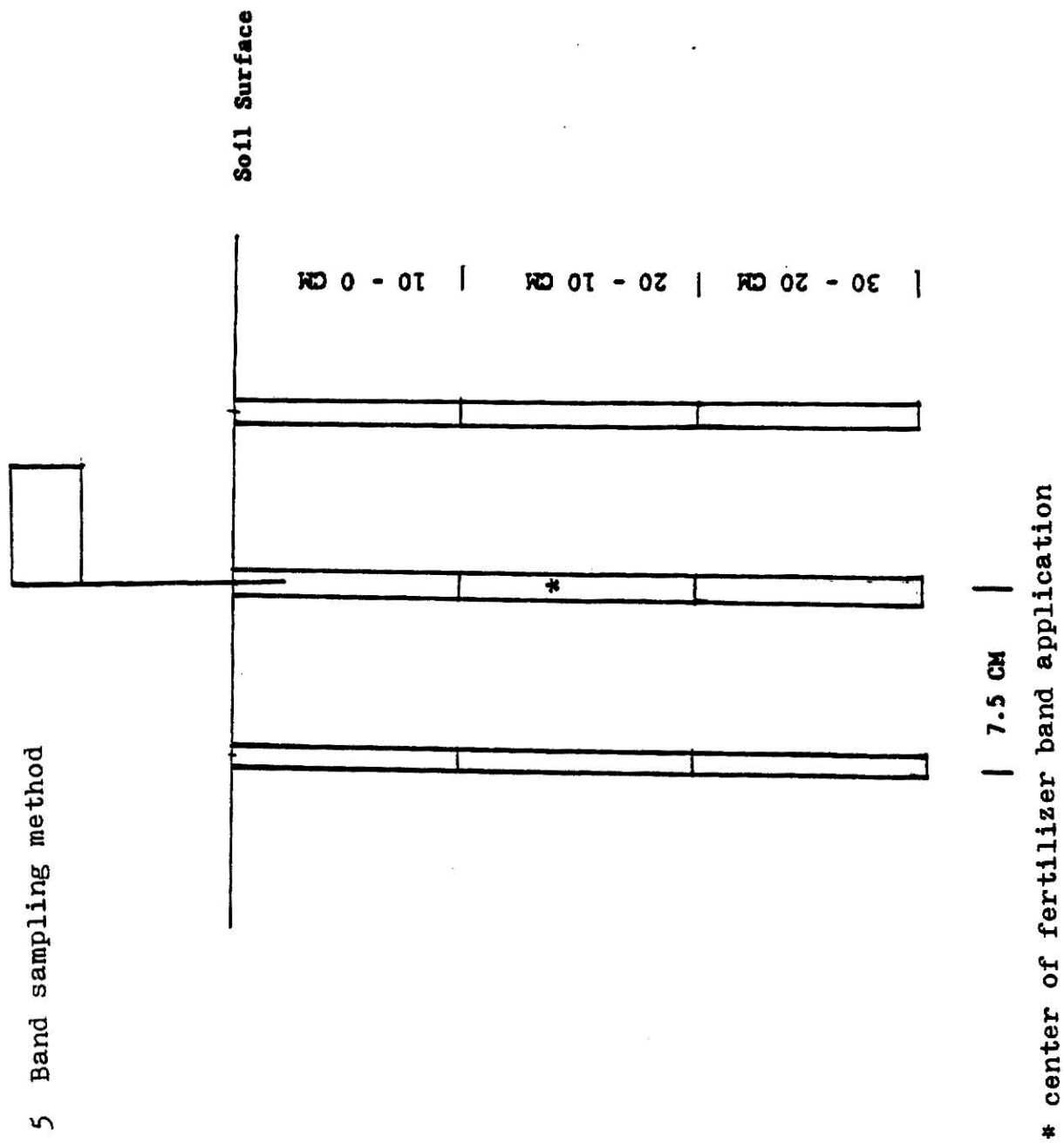
During the study period the knifed anhydrous ammonia-knifed phosphorus bands and the knifed phosphorus check bands in the time of

application studies were analyzed for inorganic soil nitrogen. The fertilizer bands were sampled using a soil probe with a 1.9 cm inner diameter. Soil samples were taken to a 30 cm depth and separated into three equal depth increments. One core was taken directly over the center of the band which had been marked with flags during application. Two more cores were taken 7.5 cm from the first, one on either side of the band and composited with the center core according to depth. This procedure (Fig. 5) was repeated three times for each plot and the samples were composited. This resulted in a 0-10, 10-20, and 20-30 cm depth sample from each plot. Where flags were lost due to tillage operations only two sets of cores were taken near the remaining flag because alignment with the band was difficult. The samples were frozen until analysis. The undried soils were analyzed for ammonium and nitrate plus nitrite content on an oven dry weight basis. Soil pH was also measured for the final sampling date.

Tissue samples were taken in the spring at the boot stage. Samples were taken by random pulling of plant leaves and stems while walking down the center of the plot. The samples were then oven dried by forced air ventilation at 60°C for approximately five days. chemical analysis for percent nitrogen and phosphorus in the plant samples was later performed.

The plots were harvested with a Model E Allis Chalmers combine equipped with a 1.95 meter wide header. The plots were harvested down the center of the plot using the whole 9 m length. On the post-emergence applications only the area between the wheel tracks was harvested because of stand damage by the tractor tires during application of fertilizer

Figure 5 Band sampling method



treatments. The grain was collected from the auger leading to the grain bin and weighed on a mounted scale. A subsample was then taken for percent nitrogen, phosphorus, and moisture content analysis. All grain weights were adjusted to 12.5% moisture.

Table 2 Dates for Field Study Operations

Site	Fertilizer Application	Planting	Band Sampling	Tissue Sampling	Grain Harvest
Jackson County	8/30/79*	9/--/79	9/17/79	4/24/80	7/1/80
	12/20/79		10/11/79		
			1/3/80		
			4/24/80		
Dickinson County	8/13/79	10/30/79	8/28/79	5/19/80	6/27/80
	9/12/79*		9/25/79		
	12/21/79		10/26/79		
			1/4/80		
			5/23/80		

* N-Rate Studies were applied at these dates.

Laboratory Studies

Three laboratory studies of nitrification were carried out. The first was initiated to study the rate of nitrification as influenced by soil buffering capacity using different soil types, amended soils, and different rates of added ammonia. A second study was conducted to determine the amount of acidity produced by different nitrogen fertilizer sources. The third study was conducted to find the maximum pH possible for nitrification at different soil ammonia levels.

Soil Preparation

Four soils (Table 3) were obtained and allowed to air dry at room temperature. The soils were then passed through a 4.76 mm mesh screen and all visible crop residue was removed.

In addition one soil was moderately limed to pH 6.7 and heavily limed to pH 8.1 using reagent grade $\text{Ca}(\text{OH})_2$. Two soils were amended by adding $[\text{Al}(\text{OH})^{+2}]$ polymers to increase its buffering capacity. Two kilograms of these soils had 10 meq. of $[\text{Al}(\text{OH})^{+2}]$ polymer added per 100 gms of soil. This was done by mixing 200 gms of soil in 500 ml of water using a Hamilton Beach blender. Then a 100 ml solution of 1.1 M $\text{Al}(\text{OH})^{+2}$ was added to the mixture. This procedure was repeated nine times to give 1800 gms of soil in approximately 4.5 liters of solution. Then the combined mixtures were air dried and combined with 200 gms of untreated soil. One soil treated with aluminum hydroxide was limed back to its initial pH and the other soil to pH 7.0 using CaO .

Ten grams of all soils were mixed individually with 70 ml of water using a stirring bar. Then 0.1 N NaOH was added in approximately 0.5 ml increments and pH was recorded after two minutes of mixing each

Table 3 Soil Used for Incubation Studies

Soil Type	Classification	Location :
Vanoss silt loam	Udic Argiustoll	Sedgwick Co.
Blanket silt loam	Pachic Argiustoll	Sedgwick Co.
Hastings silt loam	Udic Argiustoll	Dickinson Co.
Pratt loamy fine sand	Psammentic Haplustalf	Stafford Co.

increment. A plot of pH versus meq. of base added per 100 gms of soil was constructed for all the soils.

All incubations used 50 gms of soil in a 250 ml erlenmeyer flask with a one hole stopper. Water content was kept at 15% by weight for the silt loams and 6% by weight for the loamy fine sand. These moisture contents were approximately 70% of field capacity. Moisture was adjusted periodically by weighing the flasks and applying water with a spray mister. Temperature was kept at 30°C. Incubations were conducted in a Freas 815 incubator. Relative humidity was moderated by placing containers of open water at the top and bottom of the incubator. Sources of ammonium were added by pipeting solutions onto the soil and mixing the soil with a stirring rod. For the first two studies incubations were done in duplicate and for the last study they were done in triplicate. Incubation periods varied in time for each study.

Buffering Capacity and pH Study

The first nitrification study used as the nitrogen sources aqua ammonia and ammonium sulfate at five rates plus a check. Ammonium content, nitrate plus nitrite content, and pH were measured approximately one hour after initial application, and at 10, 20, 30, and 40 days incubation. All four unamended soils and all amended soils were used in the study.

N-Source Acidity Study

The second study used aqua ammonia, urea, and ammonium sulfate as nitrogen sources at 100 ppm N. A check was incubated along with the three nitrogen sources. The Blanket soil was used for this study. The soil

was incubated for 20 days before adding the nitrogen sources then the same time periods as the first study were used. Again ammonium content, nitrate plus nitrite content, and pH were analyzed after each time period.

Also, the pH was monitored on 10 gms of Blanket soil in 70 ml of water as 0.02 N sulfuric acid was added in increments while stirring with a stirring bar. By using the graph obtained of the soil's pH versus meq. of acid added per 100 gm of soil and the final pH (1:7) of the incubation treatments, the amounts of acidity produced by each nitrogen source and by the check were determined. By dividing the meq. of H^+ produced by each source minus the check by the meq. of nitrate plus nitrite produced per 100 gms of soil for each source minus the check, the meq. of H^+ produced per meq. of added ammonium nitrified was calculated.

Maximum pH Study

The third study was designed to find the maximum pH value allowable for nitrification. The Vanoss soil was prepared by grinding and sieving through a fine screen (1 mm). Different amounts of CaO were added to the soil flasks and thoroughly mixed with the soil before wetting. The moist soils were incubated for seven days, then ammonia was added at levels of 30, 100, and 200 ppm nitrogen. The samples were then allowed to incubate for seven more days. The soils were analyzed for ammonium content, nitrite content, nitrate content and pH immediately after addition of ammonia and after the second week of incubation.

Activity of the second step of nitrification was calculated by finding the change in nitrate concentration. The activity of the first

step of nitrification was calculated by adding the change in nitrate level to the change in nitrite level.

Unionized Ammonia Levels

For the 100 and 200 ppm added ammonia nitrogen rates a curve of unionized ammonia in the soil solution versus pH was constructed from pH 7.5 to pH 10.5 using the Vanoss silt loam.

The soil was adjusted to high pH values in triplicate by addition of CaO to 100 gms of soil placed in a 150 ml beaker. The soils were incubated at the same temperature and moisture as the previous experiments. After one week of incubation the two rates of aqua ammonia were added.

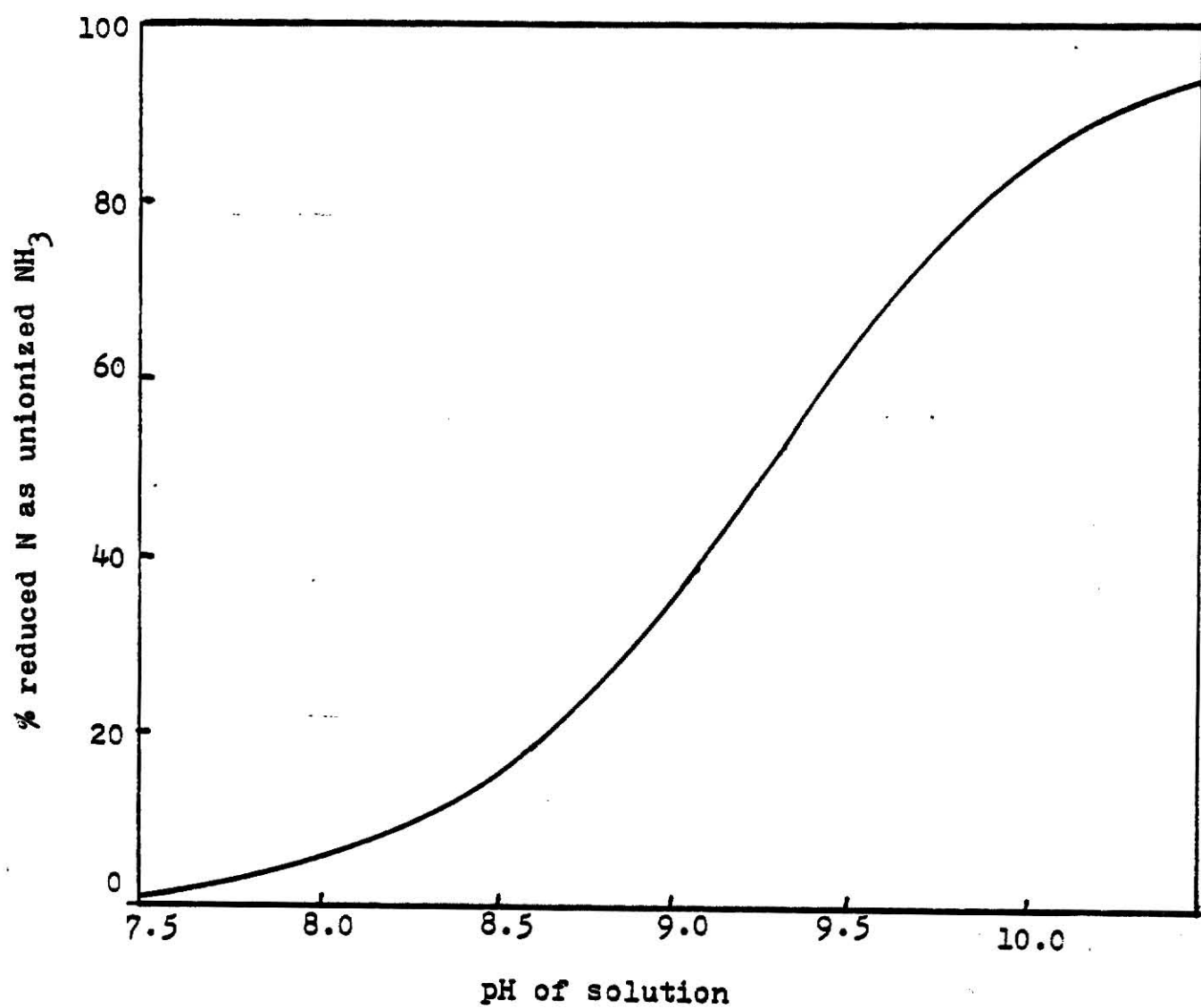
One hour after ammonia addition the soils were analyzed for extractable ammonium content and pH. The final 80 gms of soil was saturated to 55% moisture (g/g) and extracted 30 minutes later by vacuum filtration to 25% moisture. The soil extracts were analyzed for total ammoniacal nitrogen content. Since the concentration of ammoniacal nitrogen was found to be constant in a similar extraction procedure from 55% to 45% moisture to from 35% to 25% moisture, the values obtained were assumed to be similar at 15% moisture. These values of ammoniacal nitrogen content were changed to values of free ammonia content with the use of the equilibrium equation of the aqua ammonia solution given below (Marion and Dutt, 1974)

$$\frac{(\text{NH}_4^+)(\text{OH}^-)}{(\text{H}_2\text{O})(\text{NH}_3)} = 1.75 \times 10^{-5} \quad (6)$$

The relationship of ammoniacal nitrogen in solution to free ammonia over the pH range given by this equation is shown in Figure (6).

Figure 6 % unionized NH_3 versus pH

20



The values of free ammonia nitrogen obtained from the ammoniacal nitrogen concentrations were plotted against the soil pH measured initially after the addition of ammonia.

For the rates of 400, 600, and 1200 ppm added ammonia -N, soil extracts were made using all the soils from the first nitrification study except the Pratt loamy fine sand. The extracts were analyzed for ammoniacal nitrogen content. The concentrations of ammoniacal nitrogen were changed to free ammonia concentrations with the use of equation (6) and the pH values obtained in the first nitrification study.

Soil Analysis

Initial soil analysis for the field studies was performed by the Kansas State University Soil Testing Laboratory. Soil samples for all nitrification studies were analyzed by the author. These samples were broken down by hand, analyzed for moisture content, and then ten grams of moist sample were extracted with 100 ml of 2N KCl solution by shaking for one hour in a 125 ml erlenmeyer on a Eberbach shaker at medium speed. After allowing the soil to settle for 24 hours, 25 ml of extract was analyzed by the Bremner-Keeney (1966) method for ammonium and nitrate plus nitrite content reported as ppm nitrogen in oven dry soil. For the maximum pH study separate analysis of nitrate and nitrite were conducted.

Soil pH was measured on a 1:1 soil to water mixture after equilibration for 30 minutes. The C.E.C. values were obtained by extracting ten grams of soil with 25 ml of 1 N ammonium acetate buffered to a specific pH. These were allowed to equilibrate 24 hours before extraction. The soil samples were then washed with 100 ml of the ammonium acetate with a vacuum filtration apparatus, and then washed with 150 ml of 99% methanol. The adsorbed NH_4^+ was removed from the soil with 250 ml of 10% NaCl^- pH 3 wash. The extracted solution was analyzed for total ammonium content by steam distillation. The amount of adsorbed ammonium was used to calculate C.E.C. reported in meq. per 100 grams.

Tissue and Grain Analysis

Grain and dried tissue samples were ground with a Udy rotary-abrasion mill. After grinding 0.25 g of sample was digested with 2 ml of concentrated sulfuric acid. Then additions of one ml of 30% hydrogen peroxide (Linder and Harley, 1942) were added with heat (375°C) applied until the digest solutions remained clear. The digested samples were then brought to a volume of 50 ml using distilled water. Nitrogen and phosphorus determinations were made using a Technicon Auto Analyzer (T.I.S. No. 334-74, 1977).

Nitrogen was determined by the reaction of sodium salicylate, sodium nitroprusside, sodium hypochlorite, and ammonia in a buffered alkaline medium. The ammonia-salicylate complex formed was measured with a spectrophotometer at 660 nm.

Phosphorus was determined by the reaction of orthophosphate with molybdate ion and antimony ion followed by reduction with ascorbic acid at an acidic pH. The phosphomolybdenum complex formed was measured with a spectrophotometer at 660 nm.

Grain nitrogen percent was multiplied by 5.7 to estimate grain protein.

Statistical Analysis

All data with multiple replications was analyzed by the Statistical Analysis System (SAS) developed at North Carolina State University. This system is available at the Kansas State University Computing Center. For the field studies tissue, grain, and yield analysis are reported with least significant differences at the 5% level of significance. All other analysis is reported with covariance estimate ($\hat{\sigma}$).

RESULTS AND DISCUSSION

Field Studies

Wheat responded well to added phosphorus and nitrogen at both locations. Crop growth and yield were very good at the Jackson County site, but not at Dickinson County. The poor growth and low yields at Dickinson County were caused by low moisture in the fall, late planting, and severe bindweed infestation.

Time of Application Study

The band sampling data (Figure 7 & 8) from this study showed that for all preplant fertilizer applications sampled, the ammonium nitrogen was almost completely nitrified by the January sampling. The post-emergence fertilizer applications still had high concentrations of ammonium nitrogen at the January sampling but by May these concentrations had also been greatly reduced. This data would suggest that any differences in fertilizer placement effect on N and P utilization due to inorganic N form in preplant applications due to different N sources would probably be very limited by January due to nitrification.

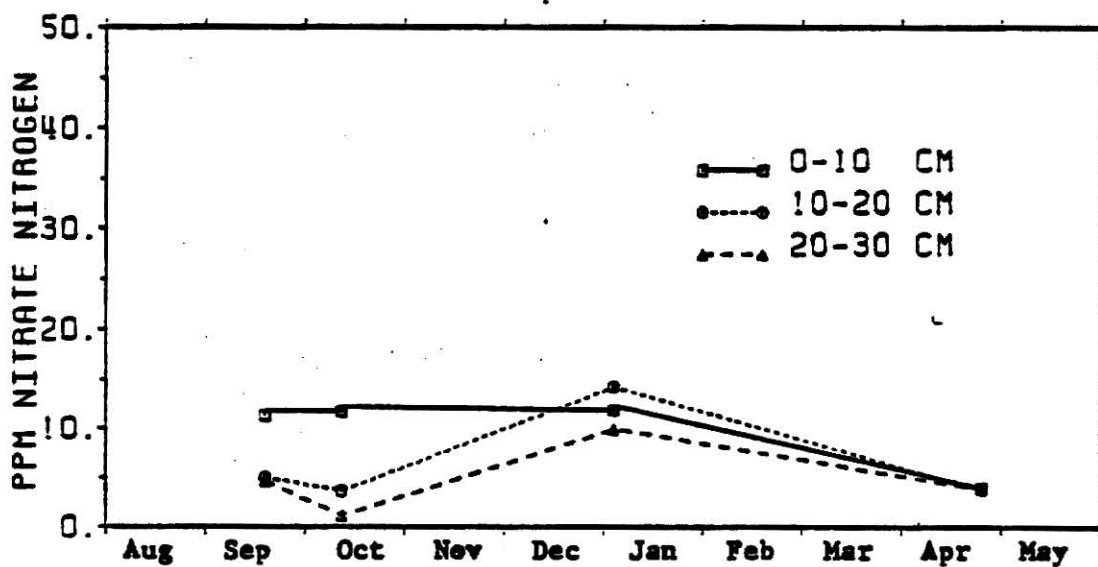
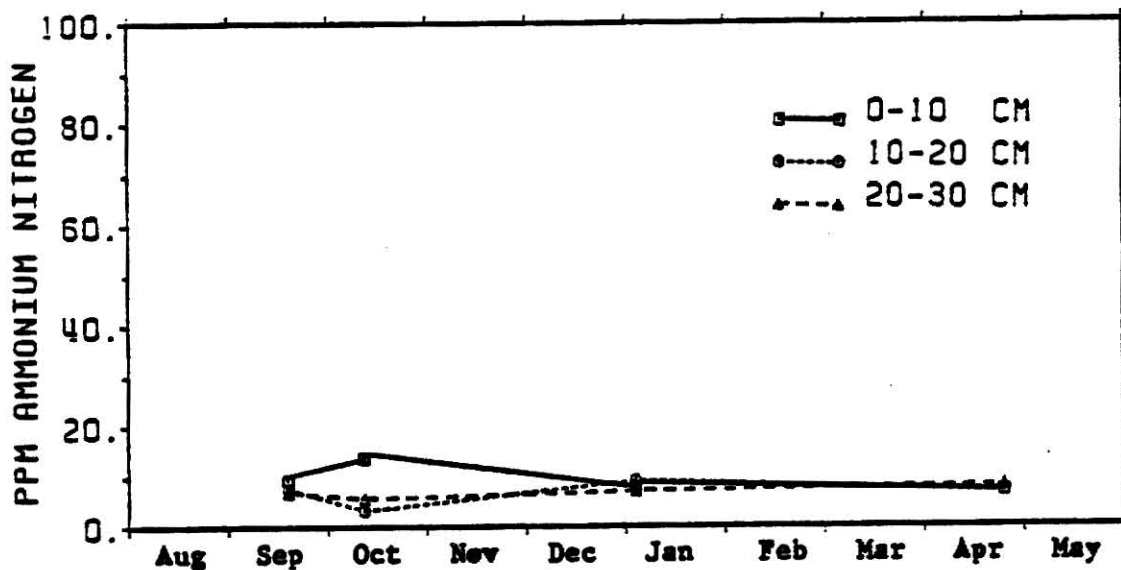
The type of band sampling employed was better suited for nitrate detection due to more uniform concentrations of nitrate across the area sampled. High levels of nitrogen were obtained for the post-emergence band samples since the band center, which had the highest nitrogen concentration, was more well defined and more accurately sampled. Since the knife mark was visible the exact position of the band center was known and the center probe always hit this band center.

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Figure 7 Change in ammonium concentration and nitrate plus nitrite³⁴ concentration in fertilizer lands sampled in Jackson Co.

13 KG/HA N 19 KG/HA P
SEPTEMBER
JACKSON COUNTY



100 KG/HA N 19 KG/HA P
SEPTEMBER
JACKSON COUNTY

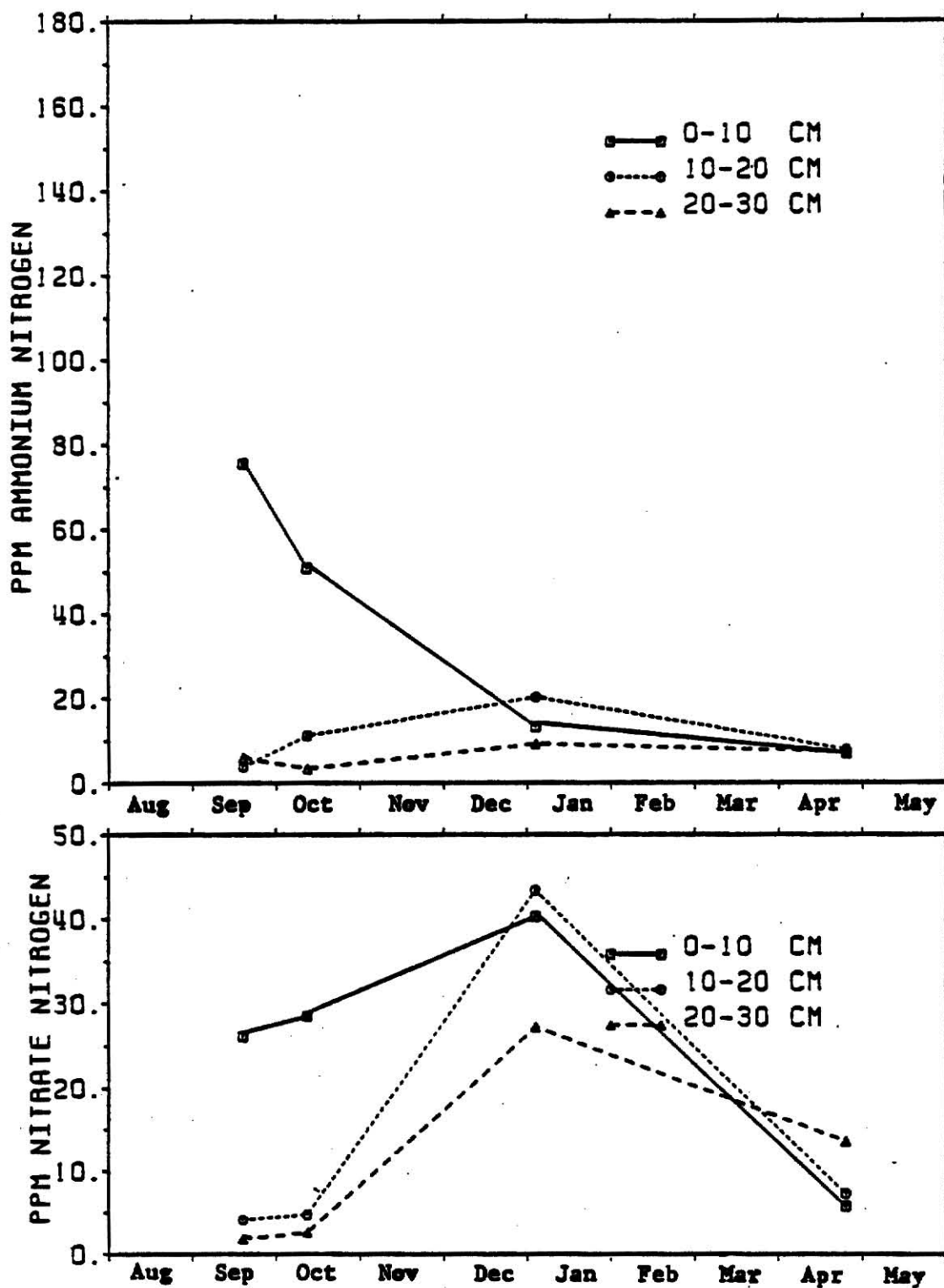
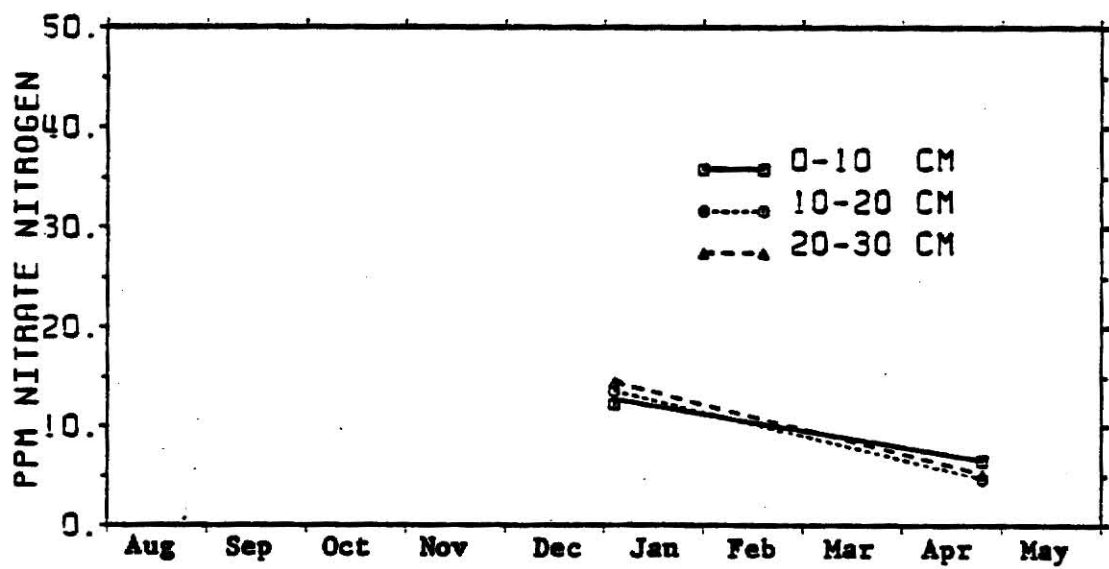
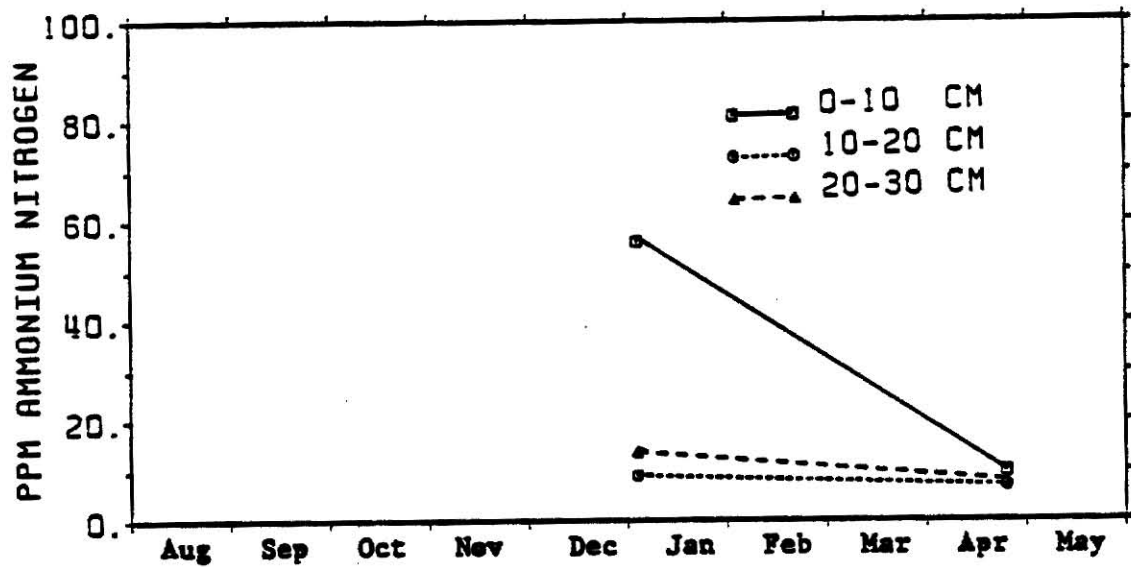


Figure 7 continued

13 KG/HA N 19 KG/HA P
DECEMBER
JACKSON COUNTY



100 KG/HA N 19 KG/HA P
DECEMBER
JACKSON COUNTY

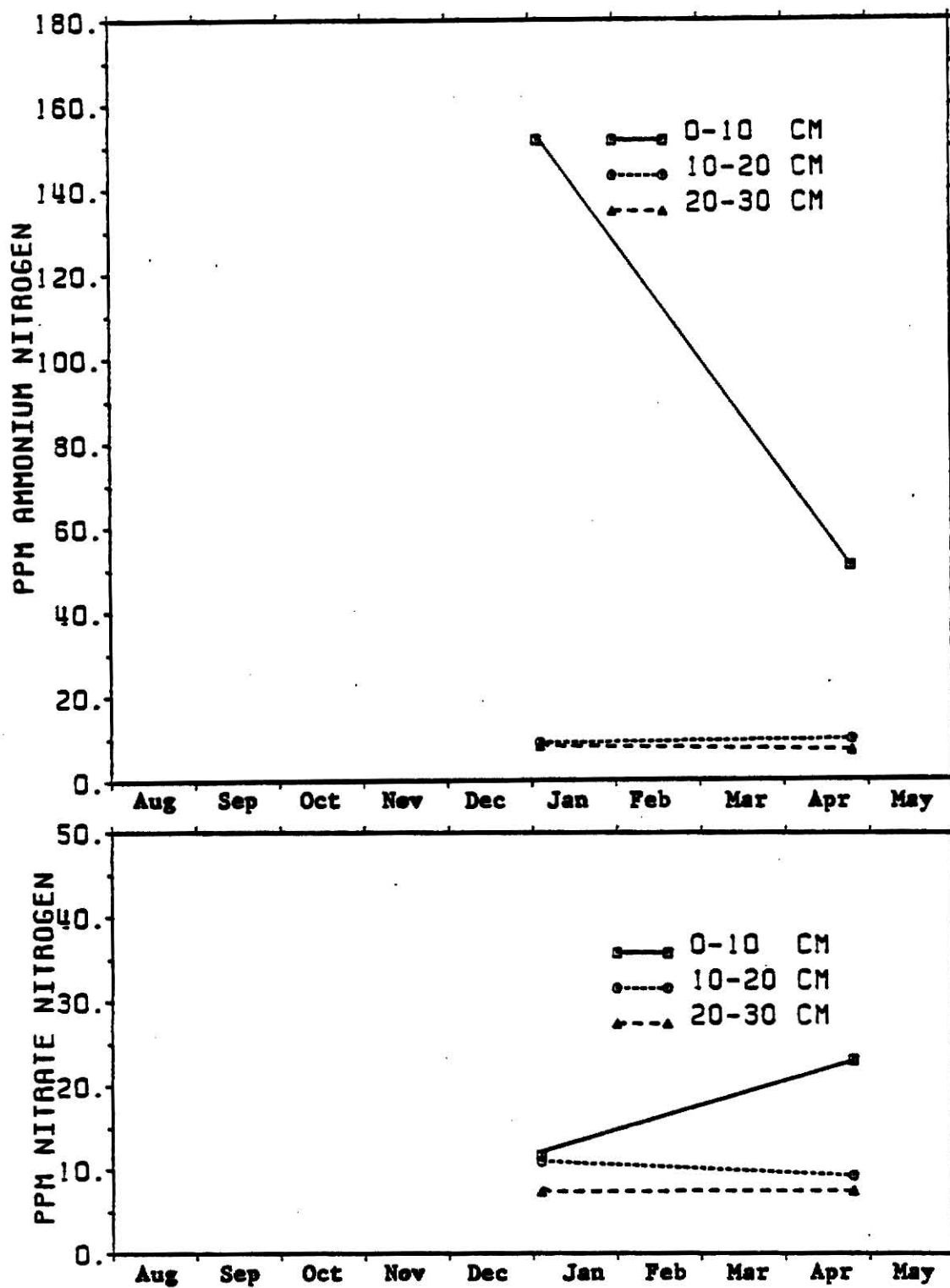


Figure 8 Change in ammonium concentration and nitrate plus nitrite concentrations in fertilizer bands sampled in Dickinson Co.

13 KG/HA N 19 KG/HA P
AUGUST
DICKINSON COUNTY

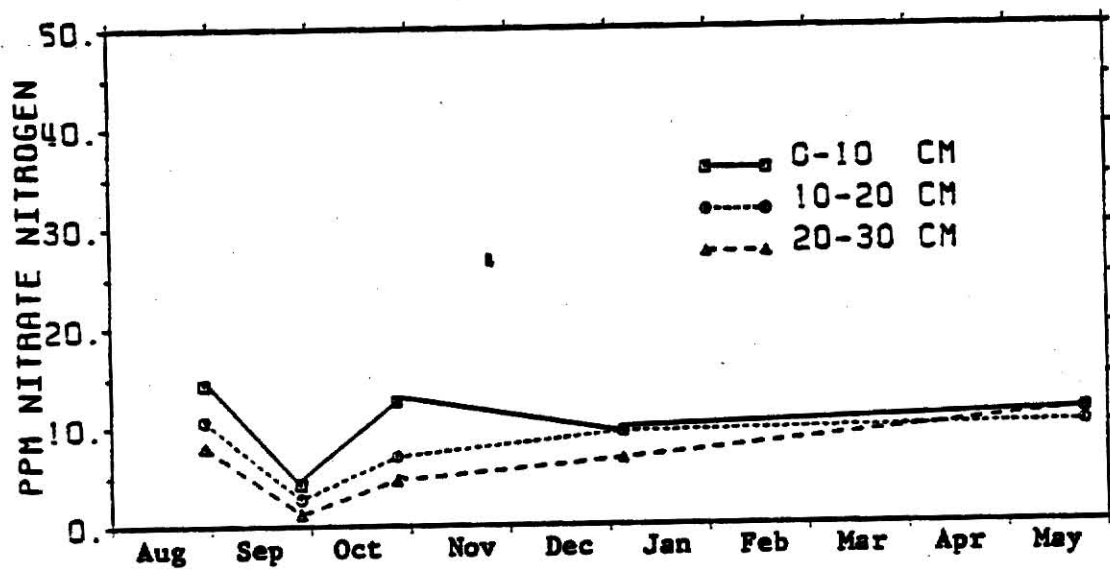
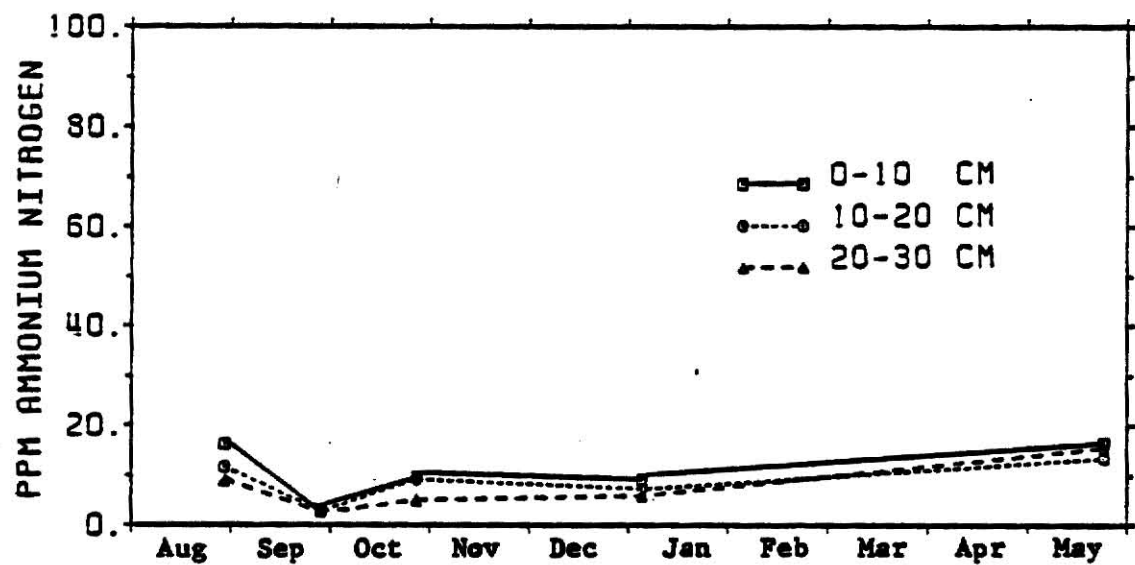


Figure 8 continued

100 KG/HA N 19 KG/HA P
AUGUST
DICKINSON COUNTY

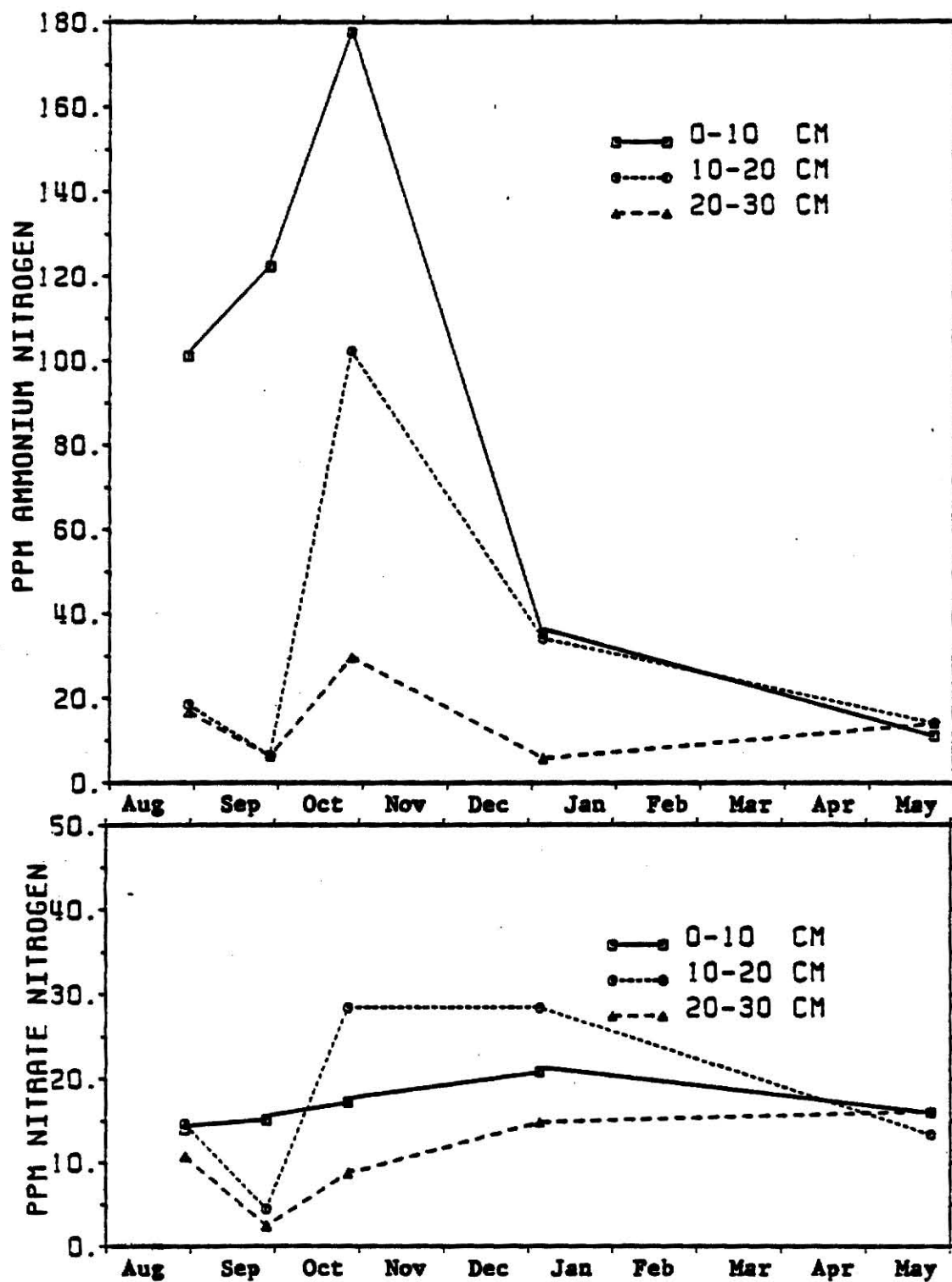
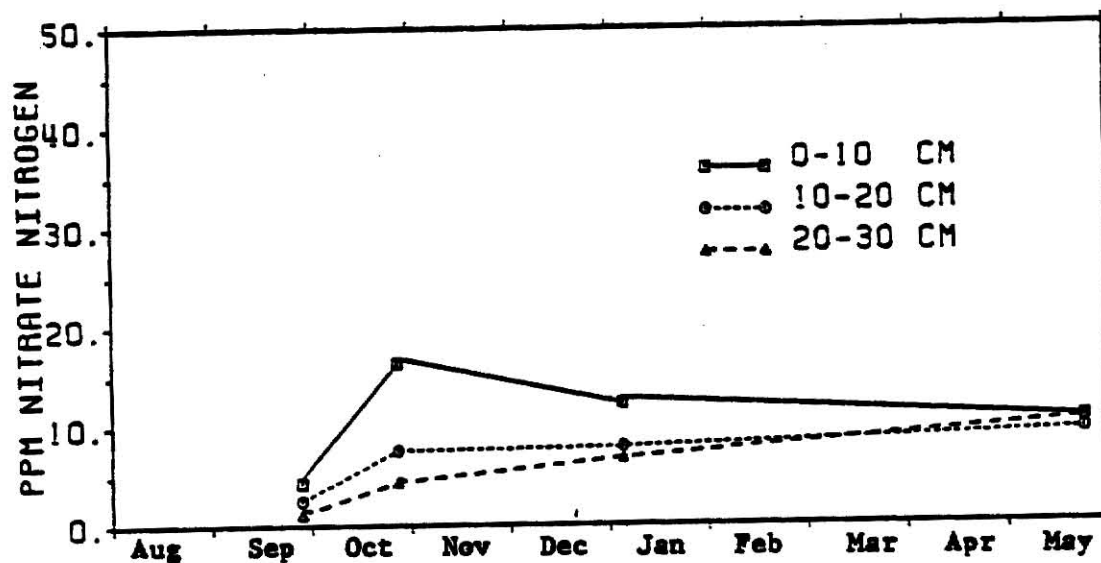
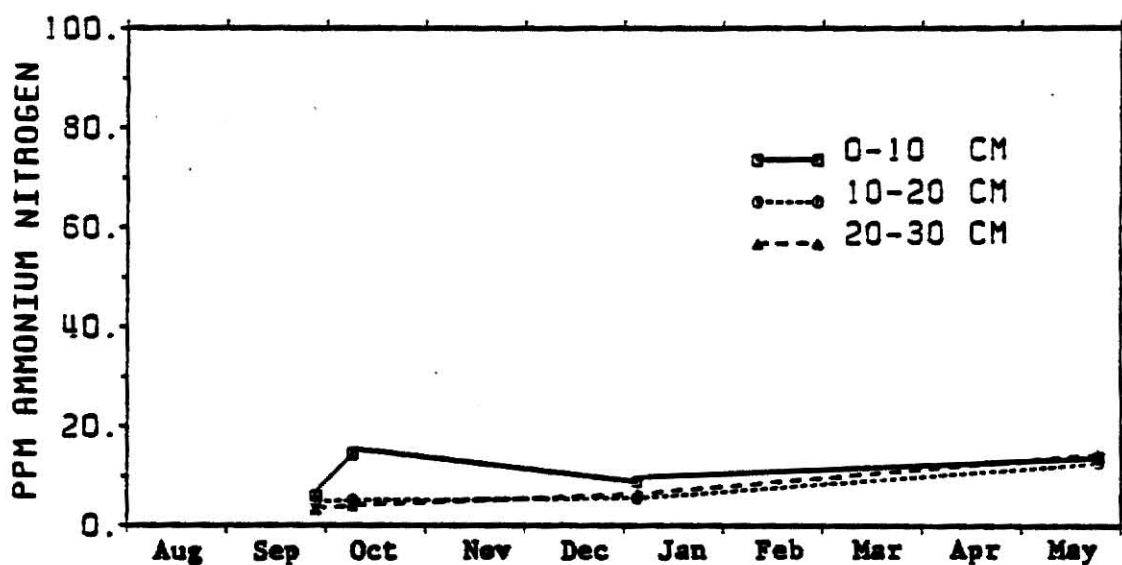


Figure 8 continued.

13 KG/HA N 19 KG/HA P
SEPTEMBER
DICKINSON COUNTY



100 KG/HA N 19 KG/HA P
SEPTEMBER
DICKINSON COUNTY

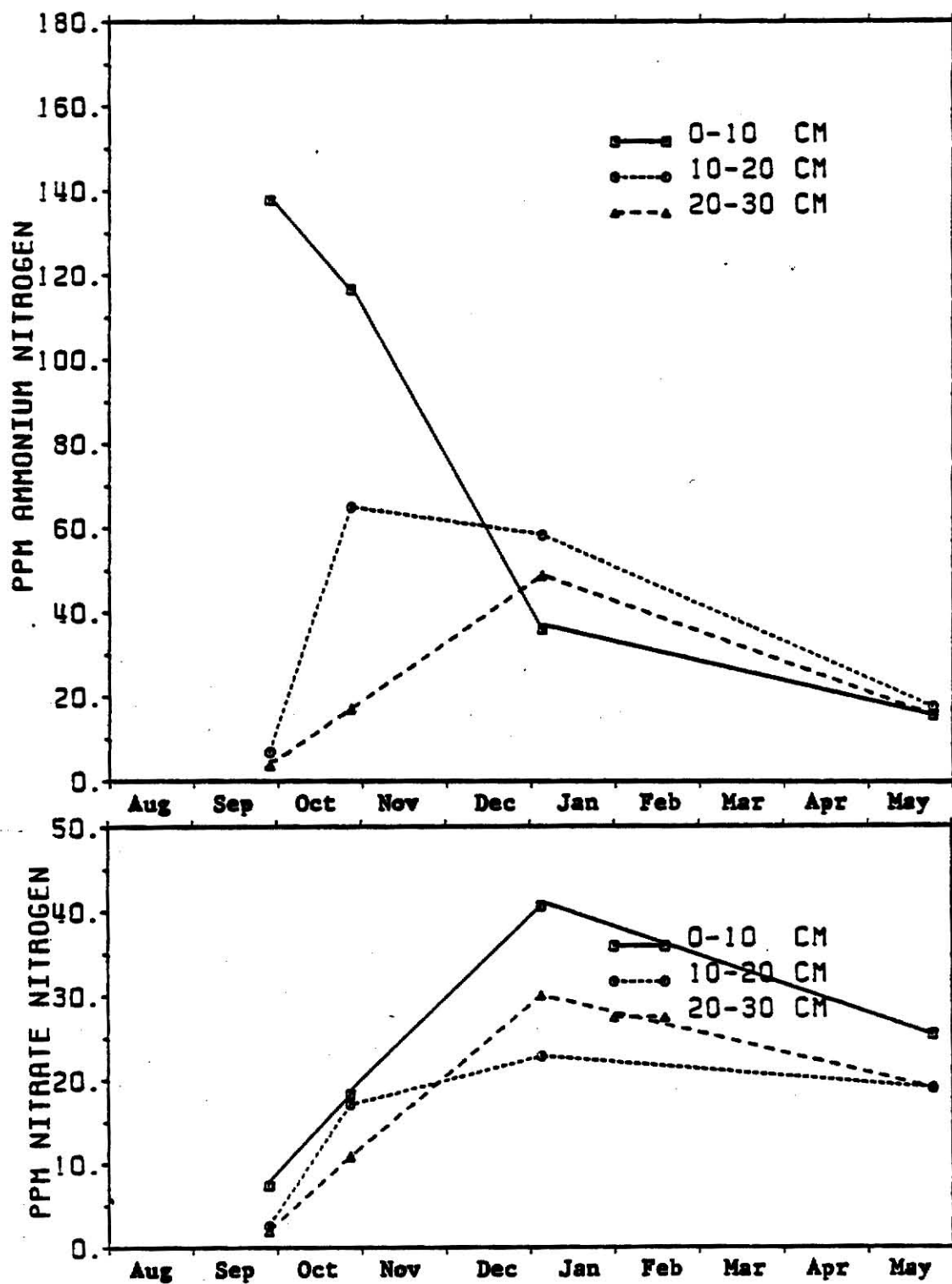
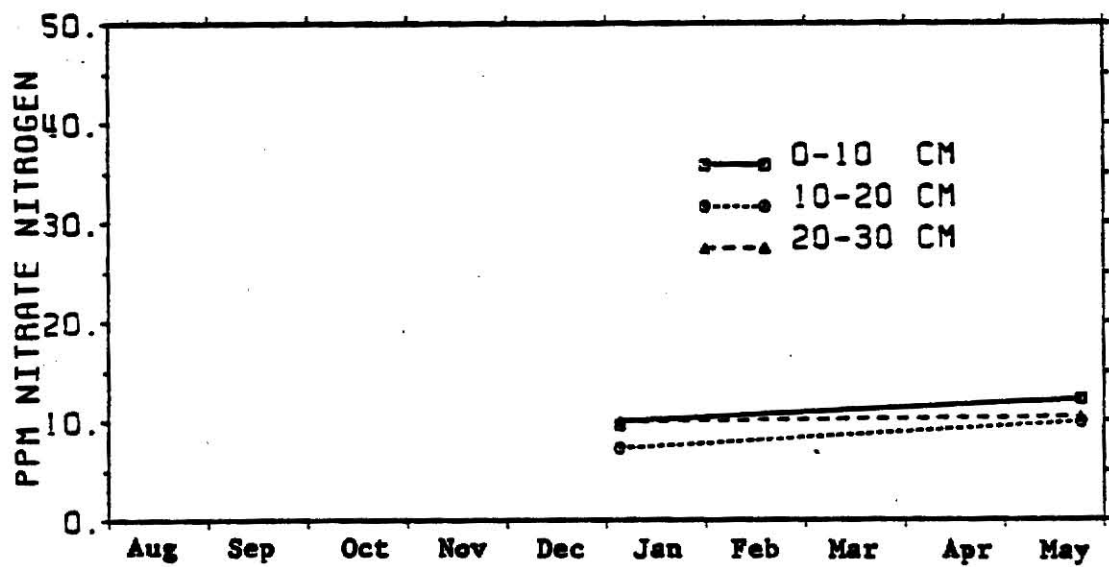
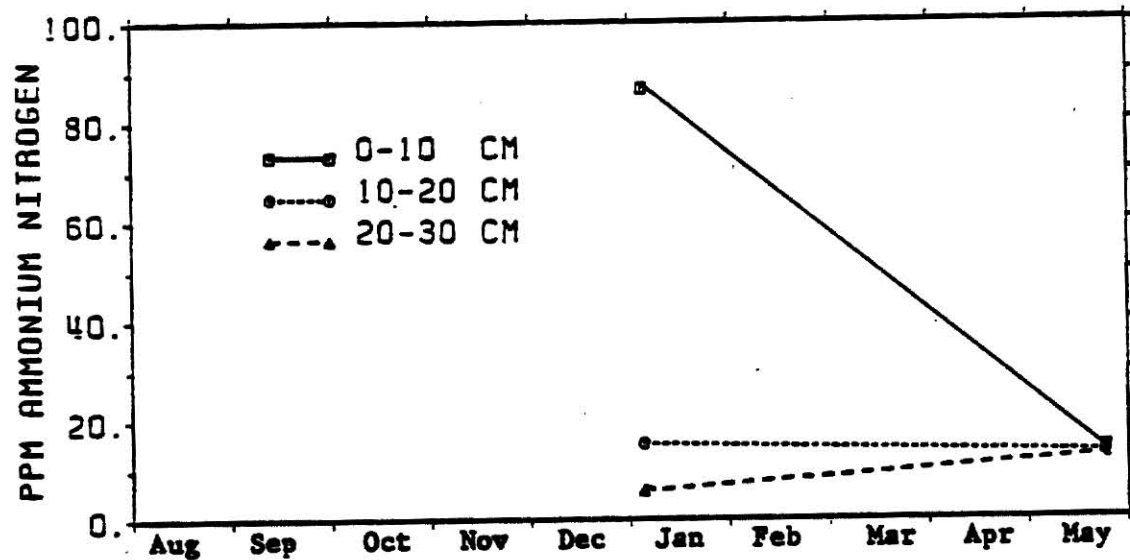
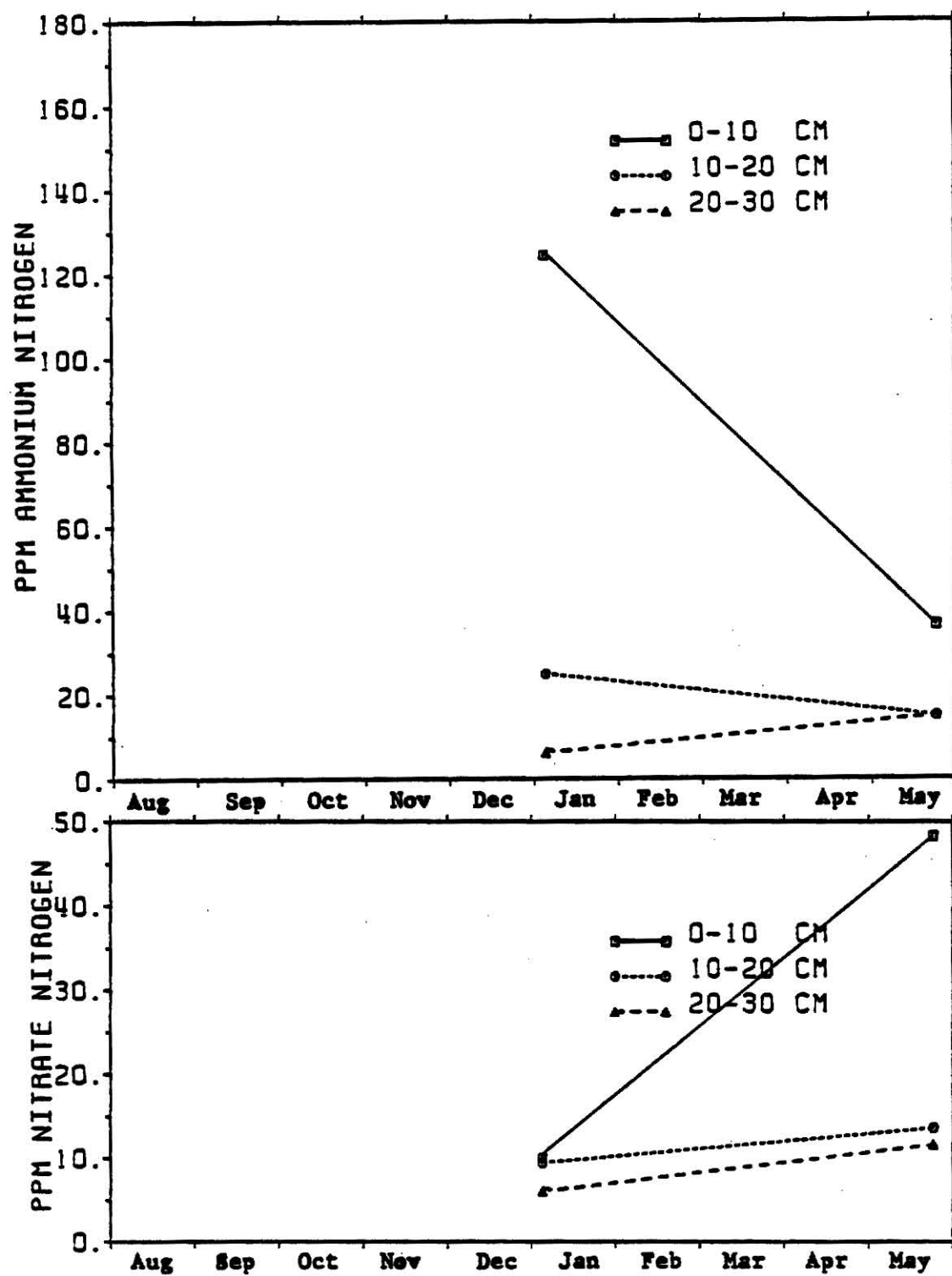


Figure 8 continued

13 KG/HA N 19 KG/HA P
DECEMBER
DICKINSON COUNTY



100 KG/HA N 19 KG/HA P
DECEMBER
DICKINSON COUNTY



Visual growth differences were easily discernible in April and May at Jackson and Dickinson Counties. There was good growth response due to added phosphorus (Fig. 9) and to knifing the phosphorus (Fig. 10). Dual knife treatments appeared superior to other treatments (Fig. 11) and preplant applications had greater growth than post-emergence applications (Fig. 12).

Yield results (Tables 4 & 5) showed a large response to added phosphorus. At both sites and all application dates the dual knifed treatments had higher yields than the other application methods except for the broadcast nitrogen-knifed phosphorus, December application at Dickinson County. At both sites yields tended to be lower for the post-emergence applications for all application methods. Tissue N content was highest for December treatments compared to other application dates. Tissue P content was highest for all knifed P treatments across all application dates. Grain protein was highest for December treatments where yields were lowest. Protein was also higher on no P or broadcast P treatments. Grain P content was higher on no N preplant treatments at Dickinson County and at Jackson County for the December treatments.

At Jackson County there was no significant difference in yield of dual knifed applications between preplant and post-emergence. Tissue and grain N and P content of these dual knifed treatments were slightly higher for the December applications compared to the September applications.

At Dickinson County the preplant dual knifed applications gave little difference between the two application dates. The post-emergence dual knifed applications showed reduced yields when no nitrification inhibitor

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Figure 9 Spring growth response of 19 kg/ha P versus no P.

Figure 10 Spring growth response of broadcast P versus knifed P.

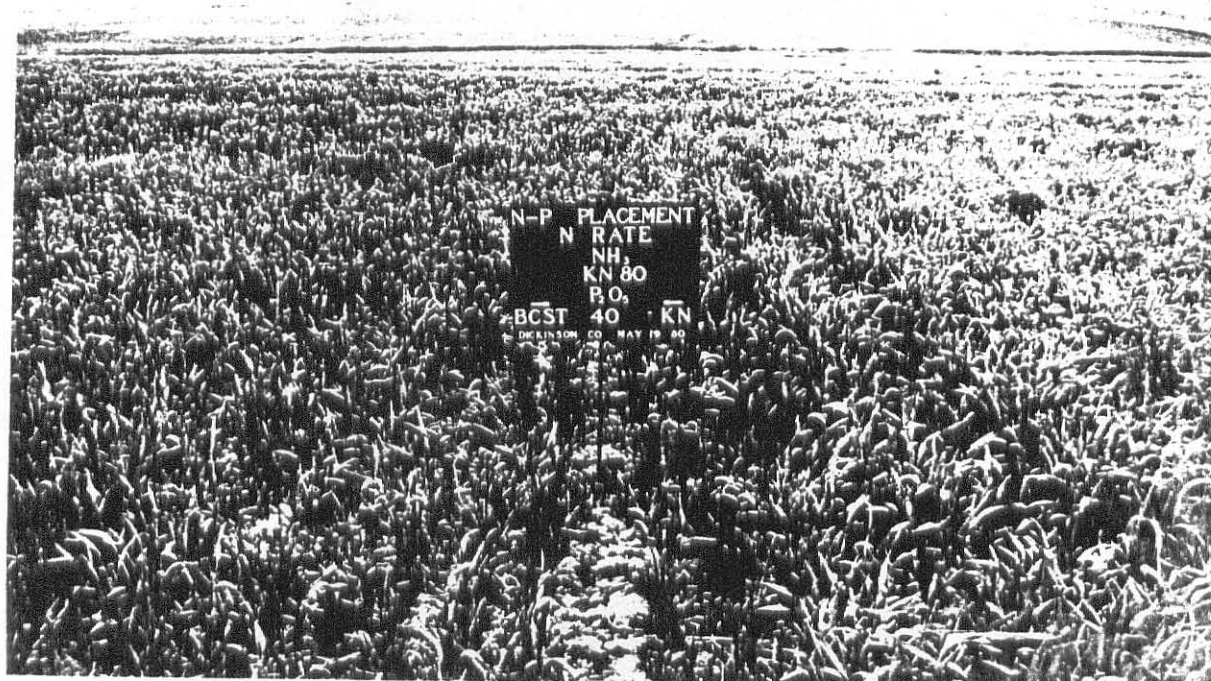


Figure 11 Spring growth response of broadcast N - knifed P
versus dual knifed N-P application.

Figure 12 Spring growth response of post-emergence versus
preplant dual knifed N-P application.



Table 4 EFFECTS OF TIMING OF N AND P APPLICATION ON WINTER WHEAT - DICKINSON COUNTY

Time	Rate		Method		N Source	Yield kg/ha	Tissue		Grain	
	N	P	N	P			%N	%P	%Protein	%P
	0	kg/ha								
	0	0	--	--	--	556	2.55	0.239	14.8	0.267
Aug.	0	19	--		--	1493	2.30	0.259	13.7	0.309
	100	19	Knife		NH ₃	1793	2.47	0.220	15.3	0.270
	100	19	B ^o cast		UAN	1420	2.59	0.233	14.9	0.251
	100	19	Knife		UAN	1801	2.78	0.243	15.3	0.259
	100	19	Knife	B ^o cast	NH ₃	1427	2.45	0.215	15.6	0.261
	100	19	Knife		NH ₃ -N.S. 1/2	1728	2.59	0.230	15.9	0.256
	100	19	Knife		NH ₃ -Dwell 1/2	2028	2.43	0.220	15.3	0.257
Sept.	100	0	Knife		NH ₃	805	2.59	0.213	15.7	0.267
	0	19	--		--	1281	2.47	0.261	14.1	0.300
	100	19	Knife		NH ₃	1698	2.54	0.235	14.9	0.261
	100	19	B ^o cast		UAN	1274	2.56	0.244	14.5	0.272
	100	19	Knife		UAN	1479	2.56	0.228	14.8	0.273
	100	19	Knife	B ^o cast	NH ₃	1318	2.50	0.223	15.8	0.275
	100	19	Knife		NH ₃ -N.S.	1720	2.34	0.226	16.0	0.262
	100	19	Knife		NH ₃ -Dwell	2174	2.73	0.228	15.7	0.257
Dec.	0	19	--		--	981	2.76	0.266	14.6	0.272
	100	19	Knife		NH ₃	1200	2.70	0.259	15.4	0.270
	100	19	B ^o cast		UAN	1376	2.52	0.252	15.1	0.268
	100	19	Knife		UAN	1362	3.11	0.280	15.9	0.268
	100	19	Knife	B ^o cast	NH ₃	761	2.76	0.214	15.7	0.258
	100	19	Knife		NH ₃ -N.S.	1552	2.83	0.263	15.7	0.266
	100	19	Knife		NH ₃ -Dwell	1501	2.90	0.273	15.6	0.273
					ISD (.05)	454	0.48	0.026	0.7	0.026

Table 4 cont.

MEAN VALUES

Time:	August	September	December	0.232	15.2	0.266
	1566	0.235	15.1	0.272		
	1244	0.258	15.4	0.268		
	ISD (.05)	0.19	0.3	0.010		0.010
Treatments:						
0	--	Knife	--			
100	Knife	Knife	NH ₃	0.262	14.1	0.294
100	B ^c cast	Knife	UAN	0.238	15.2	0.267
100	Knife	Knife	UAN	0.243	14.9	0.264
100	Knife	Knife	UAN	0.250	15.3	0.267
100	Knife	B ^c cast	NH ₃	0.217	15.7	0.265
100	Knife	Knife	NH ₃ -N.S.	0.240	15.8	0.261
100	Knife	Knife	NH ₃ -Dwell	0.240	15.6	0.263
	ISD (.05)	0.20	0.3	0.011		0.011

1/ N.S. is the nitrification inhibitor N-SERVE which was applied at 0.5 lbs. active ingredient per acre.

2/ Dwell is a nitrification inhibitor which was applied at 0.5 lbs. active ingredient per acre.

Table 5 EFFECTS OF TIMING OF N AND P APPLICATION ON WINTER WHEAT - JACKSON COUNTY

Time	Rate		Method		N Source	Yield kg/ha	Tissue		Grain	
	N	P	N	P			%N	%P	% Protein	%P
		kg/ha								
Sept	0	0	--	--	--	2364	4.08	0.237	11.2	0.367
"	100	0	Knife	--	NH ₃	2379	4.53	0.234	14.4	0.335
"	0	19	--	Knife	--	3850	4.08	0.293	10.3	0.344
"	100	19	Knife	Knife	NH ₃	4860	4.83	0.345	12.2	0.315
"	100	19	B'cast	Knife	UAN	3975	4.50	0.297	11.5	0.320
"	100	19	Knife	Knife	UAN	5131	4.97	0.343	12.2	0.293
"	100	19	Knife	B'cast	NH ₃	4297	4.67	0.278	12.8	0.317
"	100	19	Knife	Knife	NH ₃ -N.S. 1/	5043	4.73	0.353	12.3	0.312
"	100	19	Knife	Knife	NH ₃ -Lwell 12/	4421	4.71	0.295	12.3	0.314
Dec	0	19	--	Knife	--	3631	4.65	0.407	11.1	0.363
"	100	19	Knife	Knife	NH ₃	4663	5.19	0.399	13.5	0.334
"	100	19	B'cast	Knife	UAN	3275	4.70	0.400	11.4	0.351
"	100	19	Knife	Knife	UAN	4590	4.83	0.438	10.9	0.363
"	100	19	Knife	B'cast	NH ₃	2921	4.56	0.257	13.9	0.353
"	100	19	Knife	Knife	NH ₃ -N.S.	4048	4.78	0.380	12.9	0.371
"	100	19	Knife	Knife	NH ₃ -Lwell	4509	5.19	0.421	12.9	0.343
					ISD (.05)	1113	0.30	0.043	0.3	0.048

Table 5 cont.

MEAN VALUES									
Time:		September	December						
4516	0.315	4.64	12.0	0.317					
3924	0.386	4.84	12.4	0.348					
				ISL (.05)	0.11	0.017	0.3	0.019	
Treatments:									
0	19	--	Knife	--	4.34	0.350	10.7	0.354	
100	19	Knife	Knife	NH ₃	5.01	0.372	12.8	0.302	
100	19	B ^o cast	Knife	UAN	4.60	0.348	11.4	0.336	
100	19	Knife	Knife	UAN	4.90	0.390	11.6	0.328	
100	19	Knife	B ^o cast	NH ₃	4.62	0.267	13.3	0.325	
100	19	Knife	Knife	NH ₃ -N.S.	4.75	0.366	12.6	0.342	
100	19	Knife	Knife	NH ₃ -Dwell	4.95	0.358	12.6	0.329	
				ISL (.05)	0.21	0.032	0.6	0.036	
				769					

L/ N.S. is the nitrification inhibitor N-SERVE which was applied at 0.5 lbs. active ingredient per acre.

2/ Dwell is a nitrification inhibitor which was applied at 0.5 lbs. active ingredient per acre.

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was used. Higher tissue and grain N content was common to all methods of application at this date.

In the dual knifed treatments, nitrogen source showed little difference in all analysis of comparable application dates. Except in the December applications where the tissue analysis for P was slightly higher for the UAN compared to NH_3 at both sites.

The use of nitrification inhibitors decreased both yield and grain protein for the December applications at Jackson County. At Dickinson County the use of the inhibitor Dwell significantly increased grain protein and yield for the September application. For the December application at this site yield and grain protein were not significantly affected by the use of Dwell.

At Jackson County there was a significant (0.05%) interaction between time of application and method of application for tissue N% and P% and grain protein. The December treatments showed comparatively higher protein in the knifed NH_3 treatments and lower tissue P for the broadcast P treatments.

Increased yield and grain analysis of N and P of dual knifed N-P applications over other application methods was present for all application dates. This superior growth and the difference in the band sampling data suggest to the author that time of nitrification and the nitrogen ion form in the spring are not significantly important in producing a dual knifed N-P response. These studies suggest that the presence of either ammonia or nitrate in the P band is sufficient for the dual knifed N-P response. Although that is not to say that one form would not be better than the other in producing a response.

The use of nitrification inhibitors had little effect on wheat performance with early preplant applications at both locations. With December applications at Dickinson County the inhibitors affected mostly yield.

The final pH of the dual knifed bands (Appendix I) suggest that nitrification in the band area reduced the pH by only about 0.15 pH units. This pH reduction is not considered to be enough to significantly change the phosphorus availability in the soil.

If nitrification does not effect dual knifed N-P response by either its effect on nitrogen form late in the growing season or by production of acidity then it may effect crop response by controlling nitrogen movement out of the fertilizer band. More research is needed to determine what combination of these factors causes the nitrogen form effect on dual knifed N-P applications.

N-Rate Study

For this study there were also visual differences in growth in May. Differences between the N rates of 45 kg/ha and 90 kg/ha were easily seen in growth at both sites (Fig. 13) for the dual knifed N-P treatments. The differences in growth between the 90 kg/ha and 180 kg/ha N rates were less easily seen but were still present (Fig. 14) for the dual knifed N-P treatments.

Tissue and grain %N and %P and grain yield (Tables 6 & 7) indicate at Jackson County there was a strong response to both added nitrogen and phosphorus. The dual knifed N-P treatments gave the best yields even at the lowest N rate, followed by the broadcast N-knifed P. The difference between method was most apparent at the higher N rates. There was no

Figure 13 Spring growth response of 45 kg/ha N versus 90 kg/ha N in dual knifed N-P applications.

Figure 14 Spring growth response of 90 kg/ha N versus 180 kg/ha N in dual knifed N-P applications.

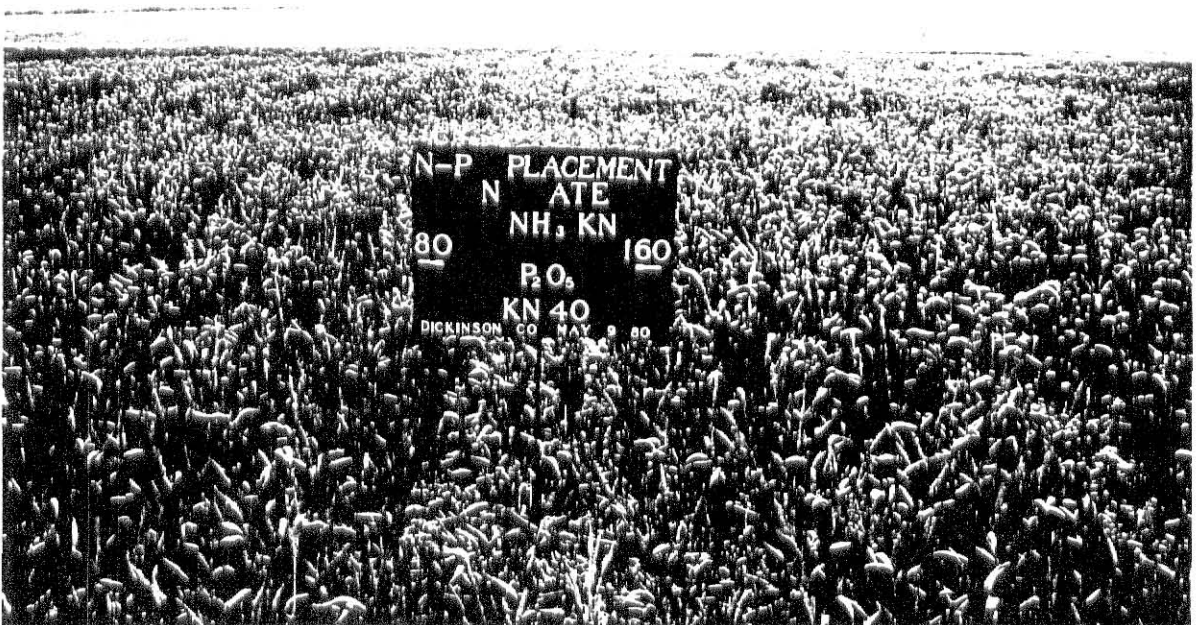
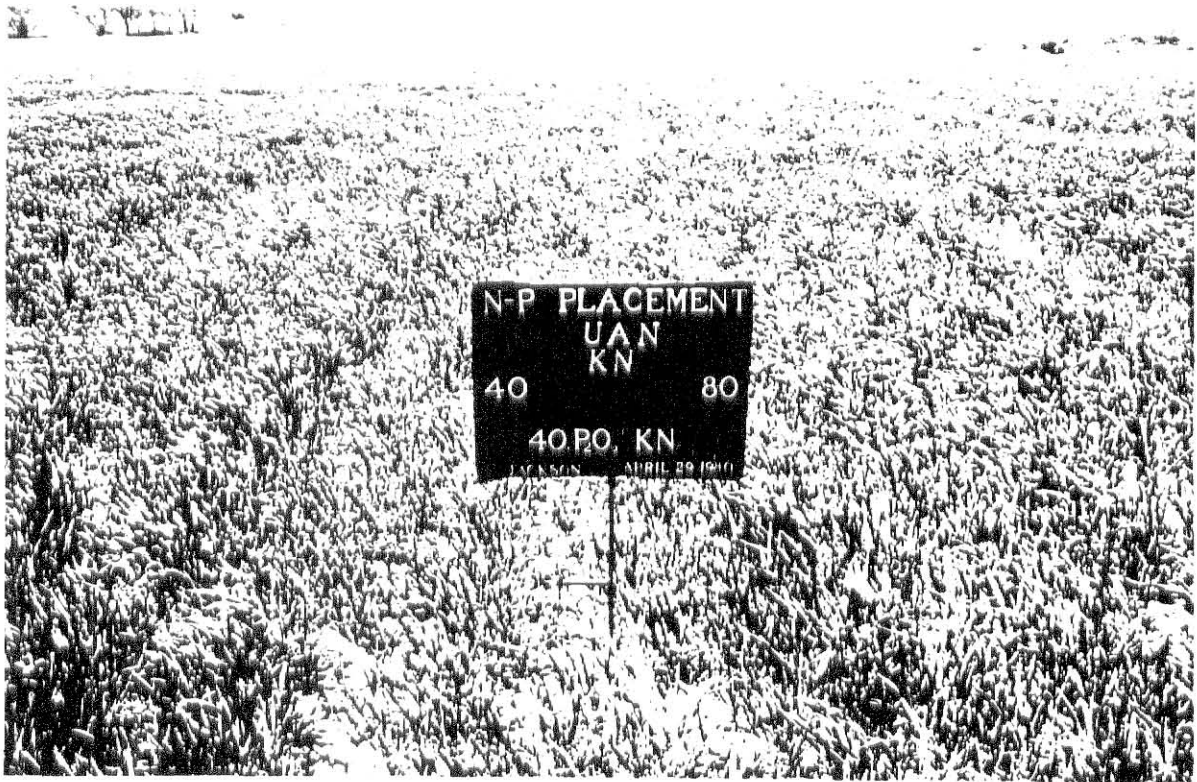


Table 6 EFFECTS OF N RATE OF N AND P APPLICATIONS ON WINTER WHEAT
(Dickinson County)

Rate		Method		N Source	Yield kg/ha	Tissue		Grain	
N	P	N	P			%N	%P	% Protein	%P
kg/ha									
0	0	--	--	--	512	2.53	0.200	14.8	0.262
90	0	Knife	--	NH ₃	630	3.01	0.194	15.8	0.265
0	19	--	Knife	--	1420	2.52	0.236	14.2	0.294
45	19	Knife	Knife	NH ₃	981	2.54	0.211	15.4	0.267
90	19	"	"	"	1845	2.39	0.216	15.2	0.251
180	19	"	"	"	2079	2.65	0.200	16.1	0.249
45	19	B'cast	Knife	UAN	1310	2.54	0.219	14.0	0.288
90	19	"	"	"	1318	2.91	0.241	14.8	0.269
180	19	"	"	"	1903	2.53	0.222	15.0	0.275
45	19	Knife	B'cast	NH ₃	1113	2.56	0.199	15.2	0.269
90	19	"	"	"	1171	2.56	0.193	15.3	0.261
180	19	"	"	"	1281	2.68	0.193	15.8	0.257
45	19	Knife	Knife	UAN	1742	2.41	0.221	14.8	0.262
90	19	"	"	"	1852	2.63	0.222	15.0	0.256
180	19	"	"	"	1808	2.51	0.204	16.0	0.249
LSD (.05)					527	0.54	0.024	0.8	0.026
<u>MEAN VALUES:</u>									
<u>Method and N Source:</u>									
Knife	Knife	NH ₃			1640	2.53	0.209	15.6	0.256
B'cast	Knife	UAN			1508	2.66	0.228	14.6	0.277
Knife	B'cast	NH ₃			1186	2.60	0.195	15.4	0.262
Knife	Knife	UAN			1801	2.52	0.216	15.3	0.255
LSD (.05)					329	0.33	0.015	0.5	0.015
<u>N Rate:</u>									
45					1288	2.51	0.213	14.9	0.271
90					1545	2.63	0.218	15.0	0.259
180					1764	2.59	0.205	15.7	0.257
LSD (.05)					285	0.28	0.013	0.4	0.013

Table 7 EFFECTS OF N RATE OF N AND P APPLICATIONS ON WINTER WHEAT
(Jackson County)

Rate		Method		N Source	Yield kg/ha	Tissue		Grain	
N	P	N	P			%N	%P	% Protein	%P
kg/ha									
0	0	--	--	--	1991	4.03	0.243	11.4	0.342
90	0	Knife	--	NH ₃	2525	4.31	0.244	12.5	0.339
0	19	--	Knife	--	2906	4.02	0.271	11.2	0.344
45	19	Knife	Knife	NH ₃	3924	4.30	0.283	11.5	0.307
90	19	"	"	"	4590	4.61	0.296	12.0	0.299
180	19	"	"	"	4656	4.70	0.307	12.9	0.290
45	19	B'cast	Knife	UAN	3448	4.34	0.258	11.9	0.325
90	19	"	"	"	4121	4.59	0.285	12.1	0.318
180	19	"	"	"	3858	4.68	0.302	12.6	0.299
45	19	Knife	B'cast	NH ₃	2994	4.39	0.248	12.6	0.328
90	19	"	"	"	3653	4.45	0.252	12.7	0.322
180	19	"	"	"	3287	4.69	0.250	13.8	0.313
45	19	Knife	Knife	UAN	3609	4.38	0.302	11.1	0.334
90	19	"	"	"	4385	4.88	0.333	11.8	0.293
180	19	"	"	"	4860	4.98	0.327	13.2	0.289
LSD (.05)					1296	0.78	0.099	2.7	0.062
<u>MEAN VALUES:</u>									
<u>Method and N Source:</u>									
Knife	Knife	NH ₃			4414	4.54	0.295	12.1	0.299
B'cast	Knife	UAN			3806	4.54	0.282	12.2	0.314
Knife	B'cast	NH ₃			3316	4.51	0.250	13.1	0.321
Knife	Knife	UAN			4275	4.75	0.321	12.0	0.305
LSD (.05)					813	0.13	0.016	0.5	0.011
<u>N Rate:</u>									
45					3462	4.35	0.273	11.8	0.324
90					4180	4.63	0.291	12.2	0.308
180					4194	4.76	0.297	13.1	0.298
LSD (.05)					688	0.11	0.014	0.4	0.010

significant difference in yield between anhydrous ammonia and urea-ammonium nitrate with the dual knifed applications. Differences were observed between N source at Jackson County, where the dual knifed UAN means had higher tissue %N and P than the dual knifed NH_3 although the means were not significantly higher.

At Jackson County, increasing the N rate increased tissue N content and when the phosphorus was knifed compared to broadcast it increased the tissue P content. At Dickinson County the broadcast N-knifed P treatments had the highest tissue P content and the broadcast P treatments had the lowest tissue P content.

The grain protein content always increased with N rate. However, grain protein of dual knifed treatments were no higher than other treatments at a common N rate. At Dickinson County protein was significantly higher for the knifed N treatments as compared to broadcast N. At Jackson County, protein was significantly higher for the broadcast P treatment, possibly due to decreased yields.

Grain P content decreased with an increase in N rate and was lowest in the dual N-P treatments which had the highest yields.

Finally, at Jackson County when nitrogen and phosphorus were applied separately the highest N rate (180 kg/ha) decreased yields, whereas, yields were not reduced in the dual knifed N-P treatments at 180 kg N/ha.

The fact that dual knifed N-P treatments showed a yield increase compared to the other application methods even at the highest N rate is important when considering leaching loss of nitrogen. Any leaching loss at lower N rates than 180 kg/ha would cause a reduction in the dual knifed N-P response for yield.

At Jackson County increasing the N rate from 45 to 90 kg/ha increased total grain P uptake (yield x grain %P) by 10.3% and only by 3.7% when increasing the N rate from 90 to 180 kg/ha in the dual knifed N-P treatments. When anhydrous ammonia was used for the dual knifed treatments the total grain P uptake was the same between 90 and 180 kg N/ha. None of these increases in grain P uptake were proportionately as great as the yield increases. If grain P content is taken as an indication of plant phosphorus uptake then it appears that at the higher N rates the effect of extra added nitrogen is more likely a direct yield response than on phosphorus uptake.

A field study to determine a difference in P uptake due to nitrogen ion form should be conducted at nitrogen rates that would supply both adequate nitrogen and produce the maximum amount of phosphorus availability.

The results from these two studies did tell us several important factors about nitrification in dual knifed N-P bands such as time of nitrification and amount of acidity produced by the process. But, the answer to why the different forms of nitrogen sometimes give significant differences in response to this method of application has not been found. Areas that should be further researched are nitrogen movement in the bands and nitrogen ion effect on phosphorus availability other than the pH effect.

Laboratory Studies

The plots of pH versus meq. of base added for all amended and unamended soils are given in Fig. (15). The curves are parallel for the silt loams at a pH below 8.0. At higher pH's the Vanoss soil has less buffering capacity. Two Kansas soils of different textures not used in these studies showed similar curves to the silt loams. These soils were a silty clay and a silty clay loam. The loamy fine sand had the least amount of buffering capacity as was expected.

Adding the $[Al(OH)^{+2}]_x$ polymers appears to have a cumulative effect on increasing buffering capacity over the pH range. The curves in these soils do not become parallel to the corresponding unamended soil until a very high pH is reached.

These curves were not accurate in predicting soil pH values reached after the addition of aqua ammonia even after taking into account the difference in dilution ratio for the pH readings. Higher rates of ammonia addition and soils with higher initial pH's did not show as great an increase in soil pH as would be expected from the buffering curves. This may be due to loss of ammonia at high rates of added ammonia and high pH. But, it may also be due to the fact that at high pH levels not all of the ammonia ionizes to ammonium and hydroxide ions. Unionized ammonia is important to nitrification due to its toxicity to nitrifying bacteria.

Buffering Capacity Study

Comparing the unamended soils it is seen that the Vanoss soil (Fig. 17b) and the Blanket soil (Fig. 16b) had similar nitrification rates

Figure 15 Soil Buffering Curves

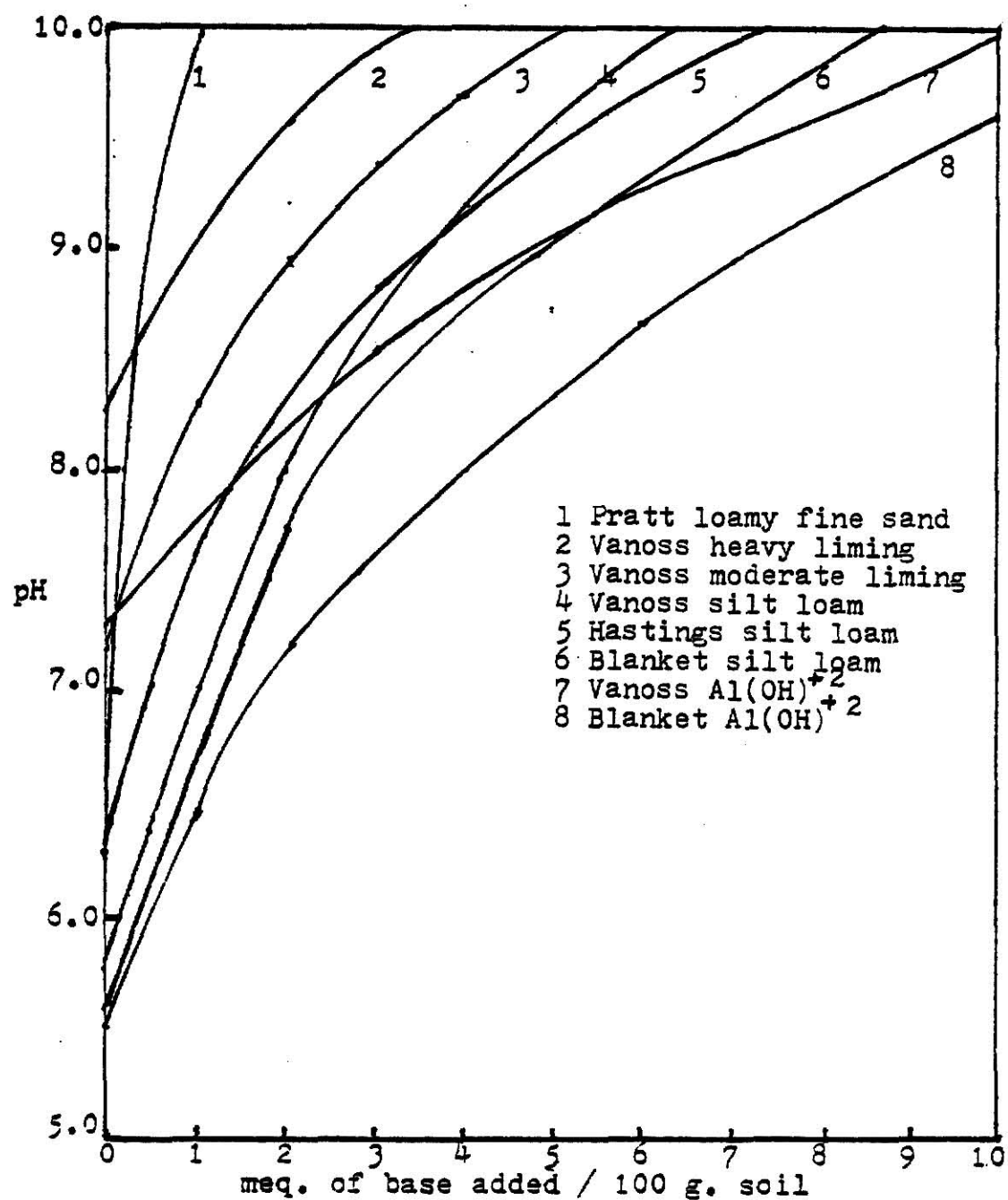
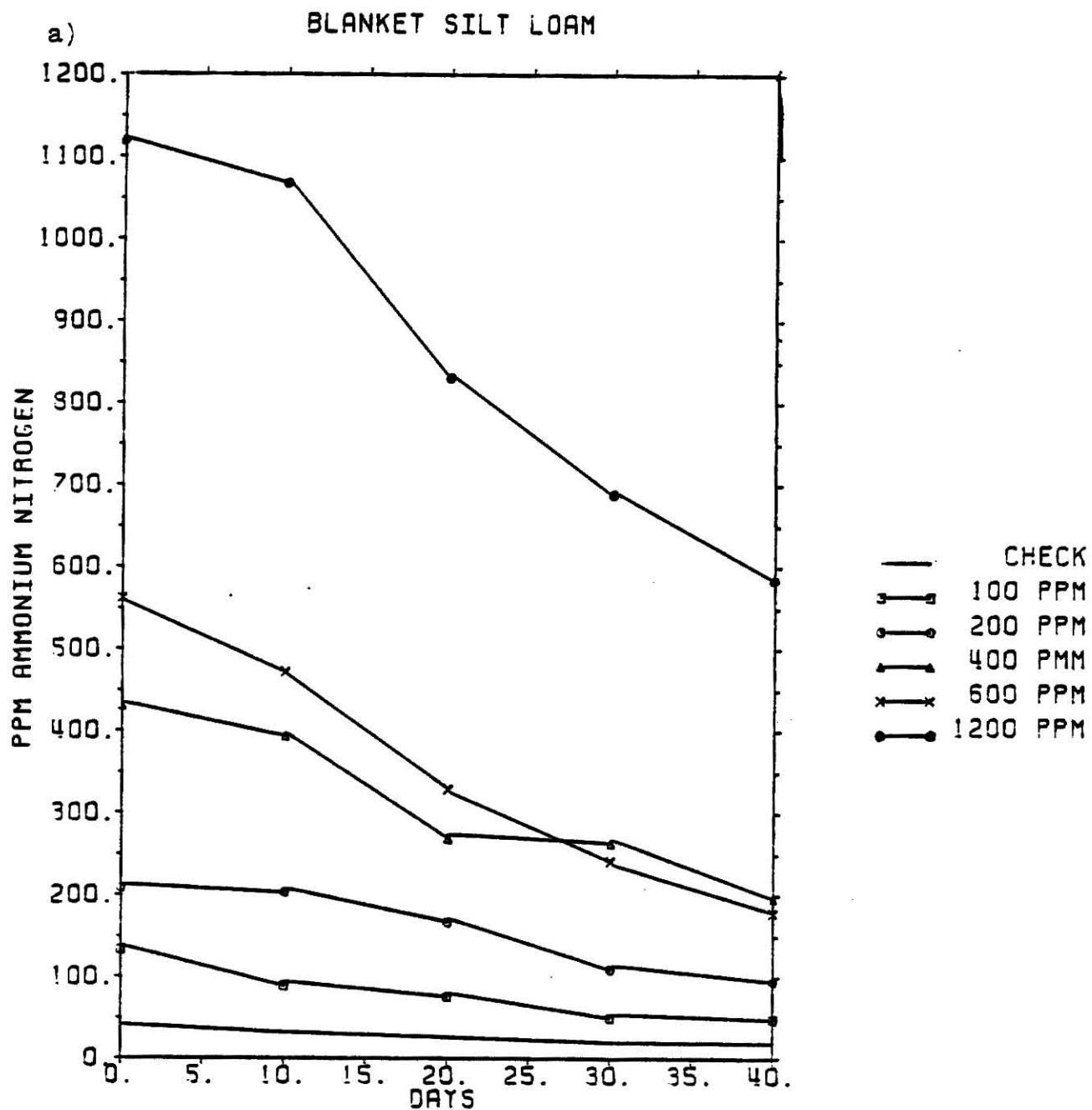


Table 8 Soil cation exchange capacities for laboratory soil types

	<u>C.E.C.</u>	<u>pH 7.0</u>	<u>pH 8.6</u>
1 Pratt loamy fine sand		3.8	3.4
2 Vanoss heavy liming		17.4	17.8
3 Vanoss moderate liming		18.3	18.3
4 Vanoss silt loam		17.1	17.2
5 Hastings silt loam		26.2	26.7
6 Blanket silt loam		17.8	18.5
7 Vanoss Al(OH) ₃ +2		21.9	17.4
8 Blanket Al(OH) ₃ +2		18.0	17.8

Figure 16 Nitrification Curves a) change in ammonium concentration over time, b) change in nitrate plus nitrite concentration over time, c) change in pH over time.



b) BLANKET SILT LOAM

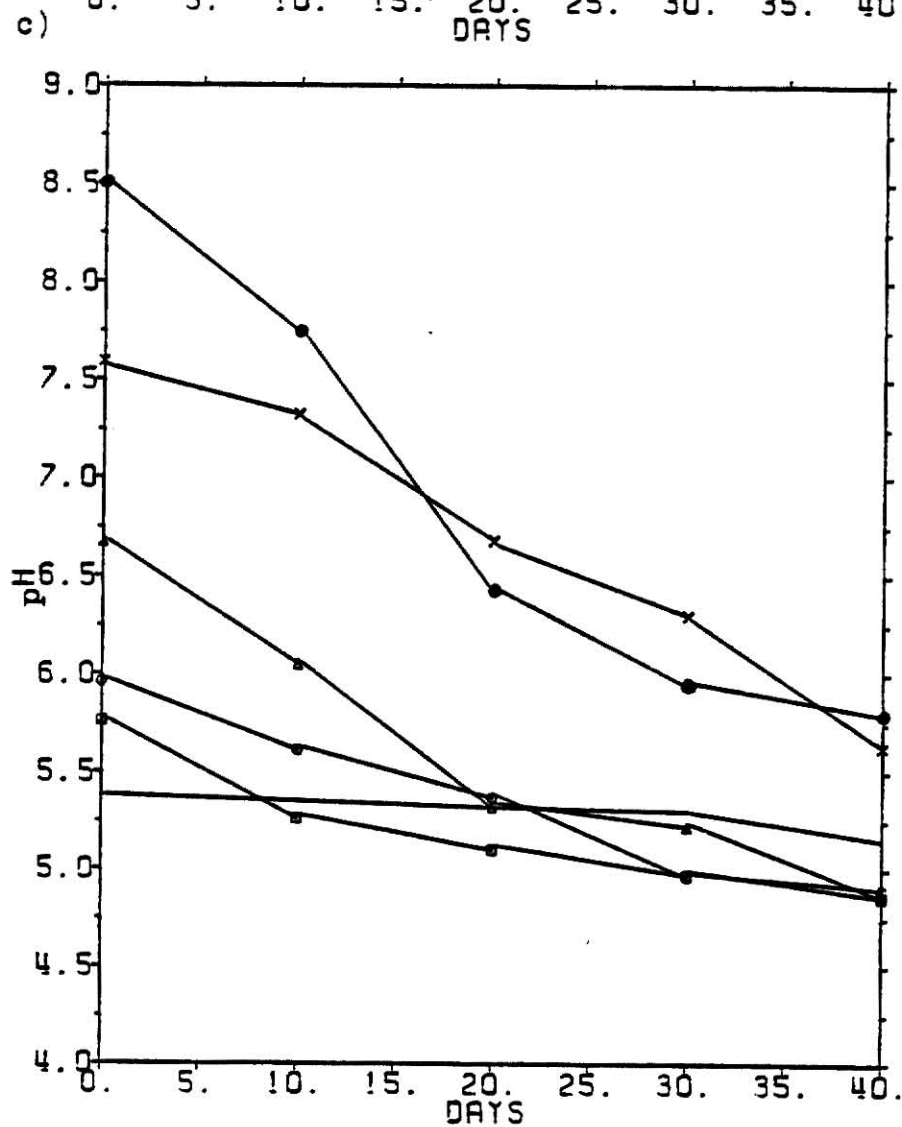
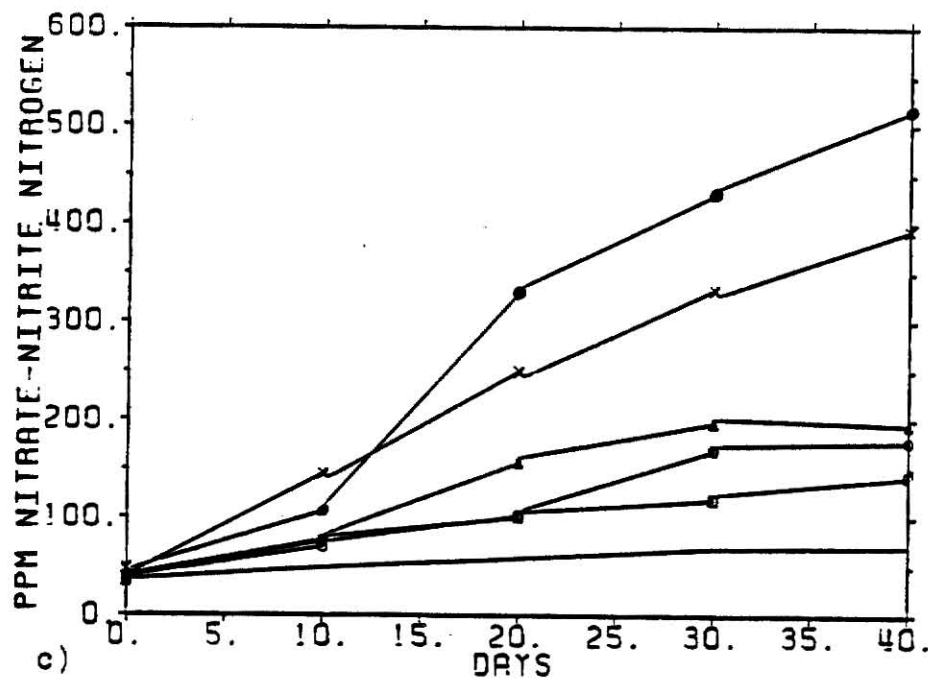
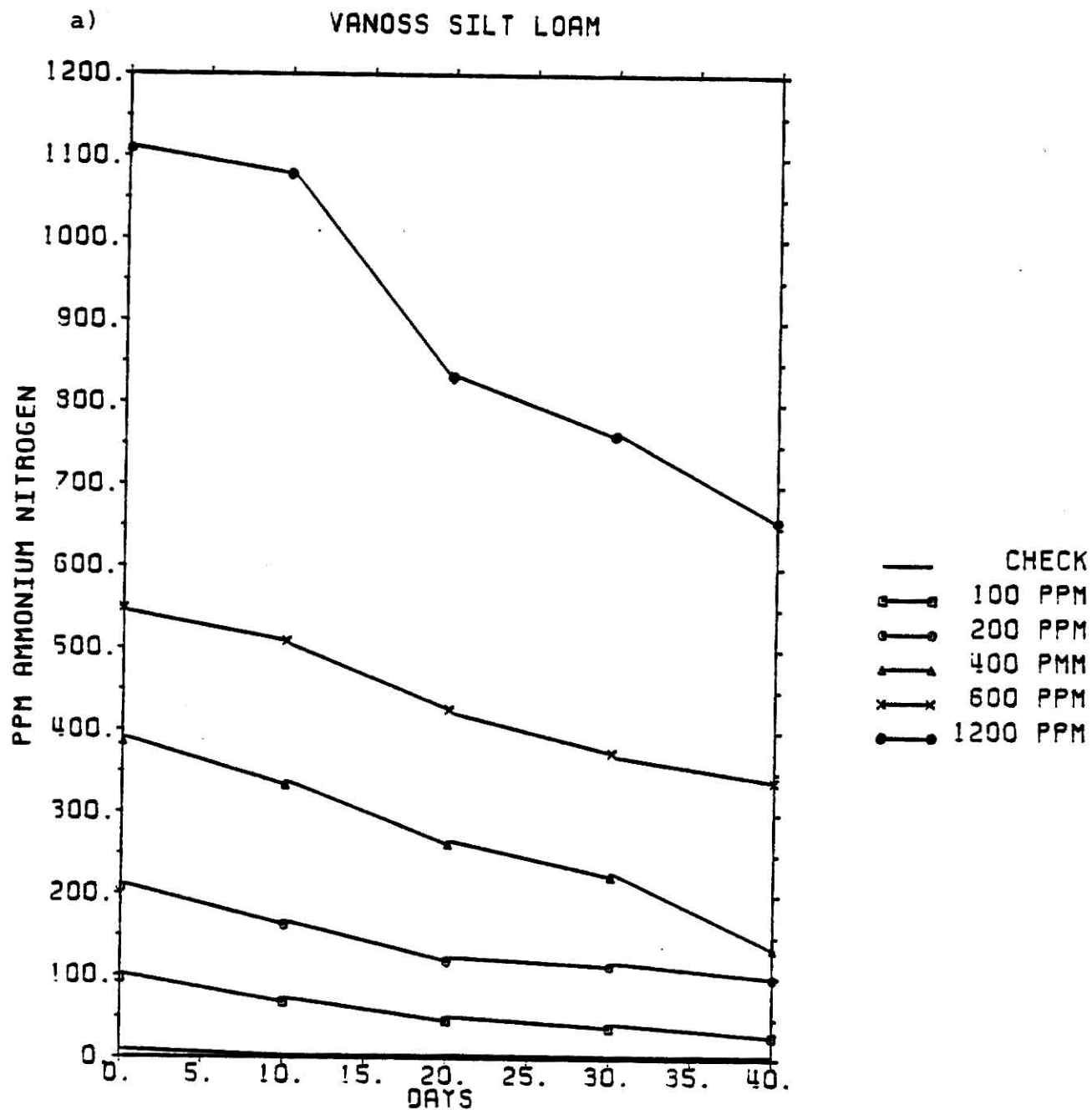
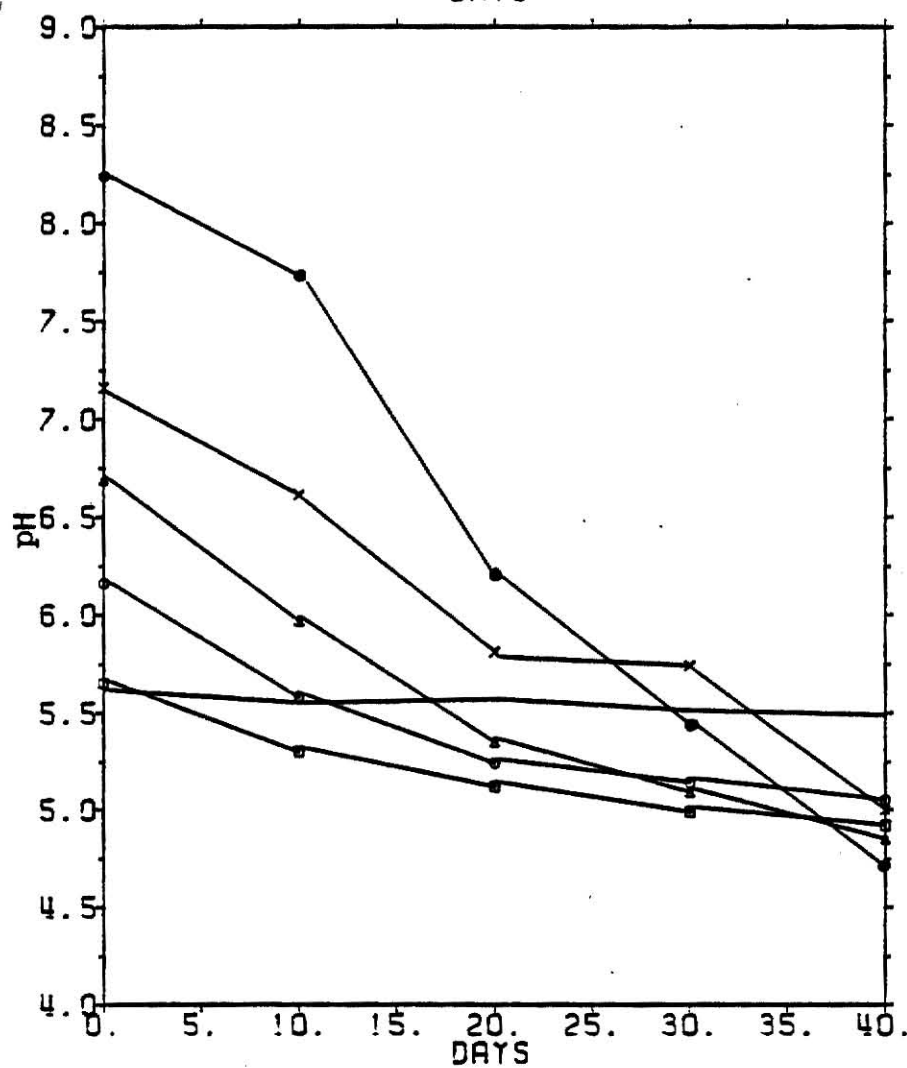
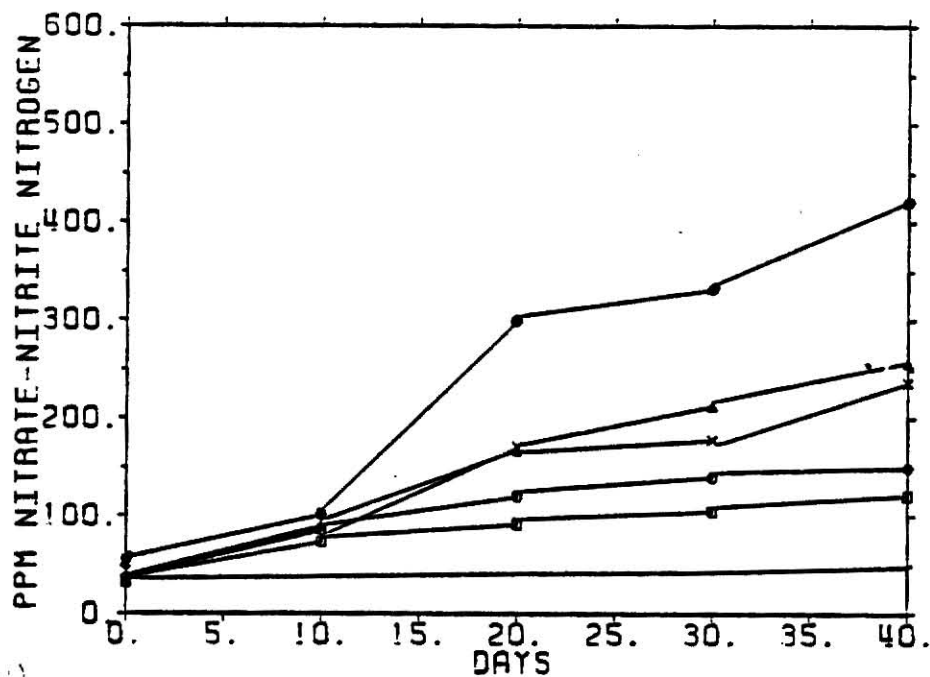


Figure 17 Nitrification Curves a) change in ammonium⁶⁴ concentration over time, b) change in nitrate plus nitrite concentration over time, and c) change in pH over time.



VANOSS SILT LOAM



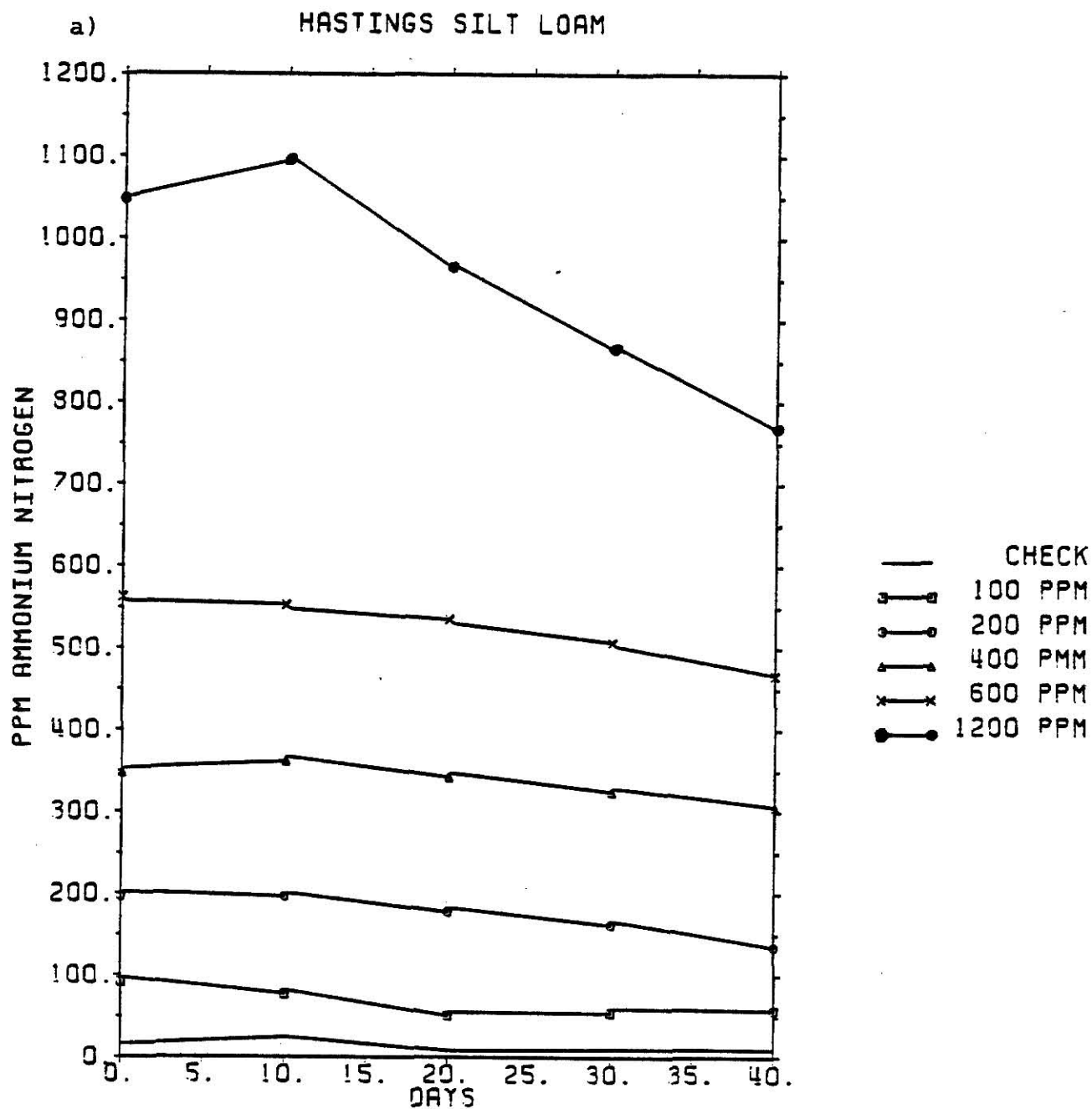
except that the two highest ammonia rates gave a higher pH and a faster nitrification rate in the Blanket soil.

The Hastings soil (Fig. 18b & c) had even lower pH values for the highest nitrogen rates and greatly reduced nitrification at all rates of added ammonia compared to the other two silt loams. Since only the highest rate of added ammonia nitrified appreciably, the inhibition appears to be caused by unavailability of the ammoniacal nitrogen to the nitrifiers. The amount of ammonium adsorbed onto the cation exchange sites may be a factor in the low nitrification rates since the Hastings' soil had the highest CEC. But, as seen in the last laboratory experiment discussed (Table 14), the levels of reduced nitrogen in solution was similar for the Hastings soil as it was for the other soils. So here it is not likely that adsorption of ammonium would be the cause of the lower rates of nitrification.

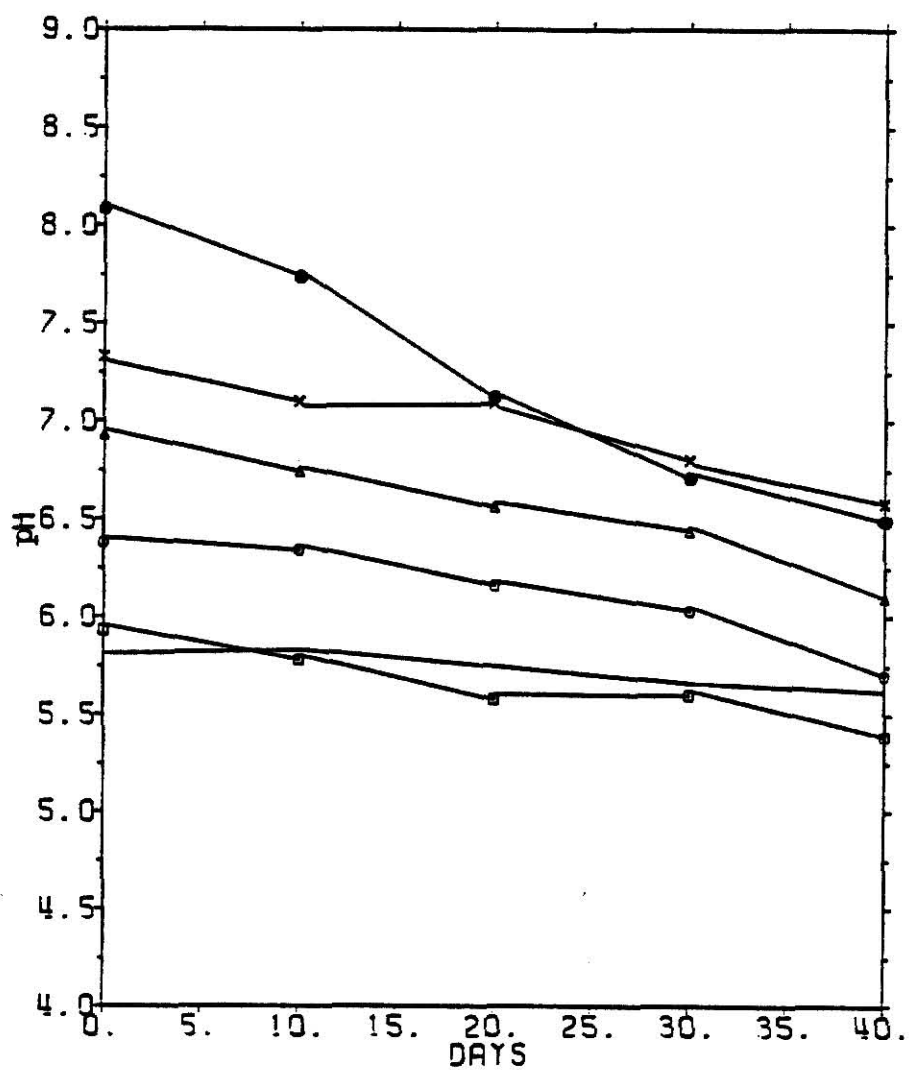
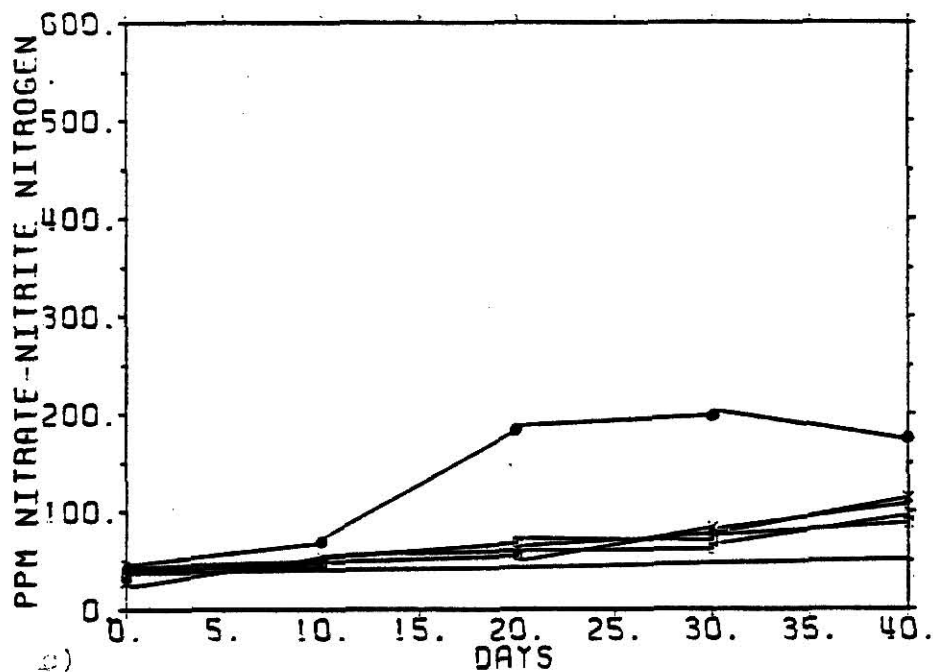
The Pratt soil which lost most of its added ammonia and was able to hold less than 300 ammonium nitrogen had very low nitrification rates (Fig. 19a & b). Toxic levels of ammonia would easily exist in the Pratt soil due to its low buffering capacity and low adsorption of ammonium onto soil particles. Low adsorption of ammonium would result in high solution concentrations of ammonium and an increased pH would cause most of this ammonium to remain unionized. Inhibition in the Pratt soil is present at pH's lower than 8.0. It is interesting to note that very high pH levels were not obtained for the first sampling date due to the rapid loss of large amounts of ammonia.

Liming the Vanoss soil generally increased nitrification (Fig. 17b, 20b, & 21b). With moderate liming the highest added ammonia rate caused

Figure 18 Nitrification Curves a) change in ammonium concentration over time, b) change in nitrate plus nitrite concentration over time, and c) change in pH over time.



HASTINGS SILT LOAM



ILLEGIBLE DOCUMENT

**THE FOLLOWING
DOCUMENT(S) IS OF
POOR LEGIBILITY IN
THE ORIGINAL**

**THIS IS THE BEST
COPY AVAILABLE**

Figure 19 Nitrification Curves a) change in ammonium concentration over time, b) change in nitrite plus nitrate concentration over time, and c) change in pH over time.

PRATT LOAMY FINE SAND

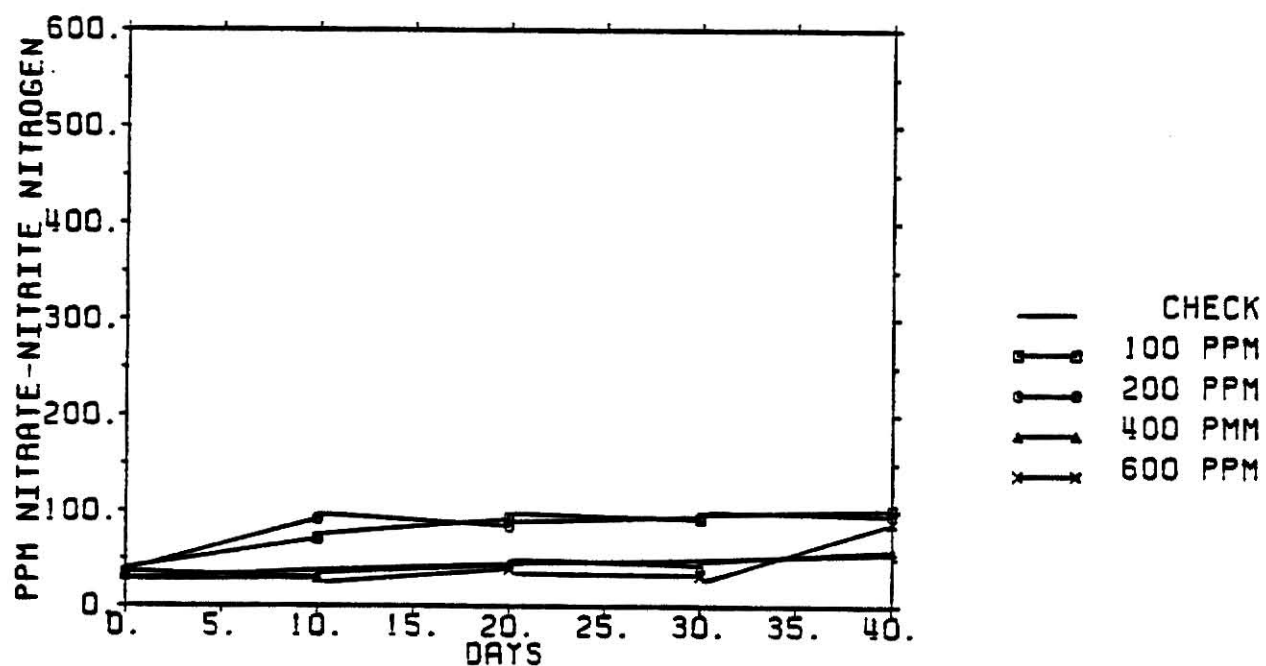
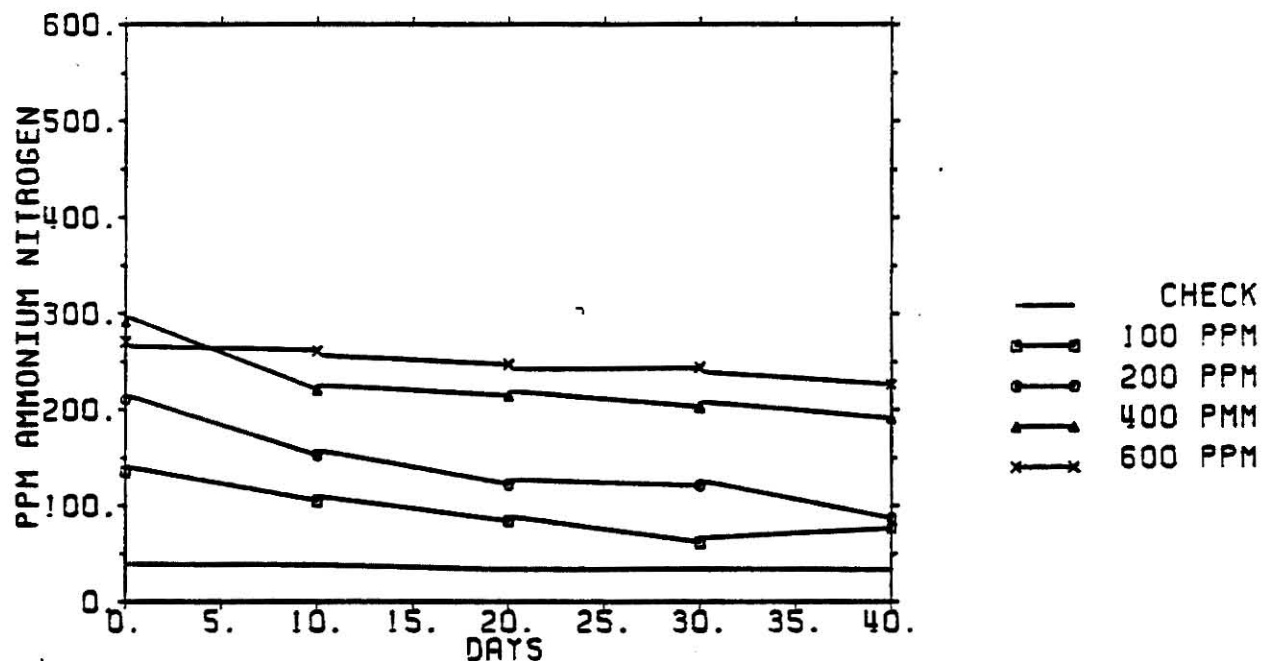


Figure 19 cOnt. Nitrification Curves

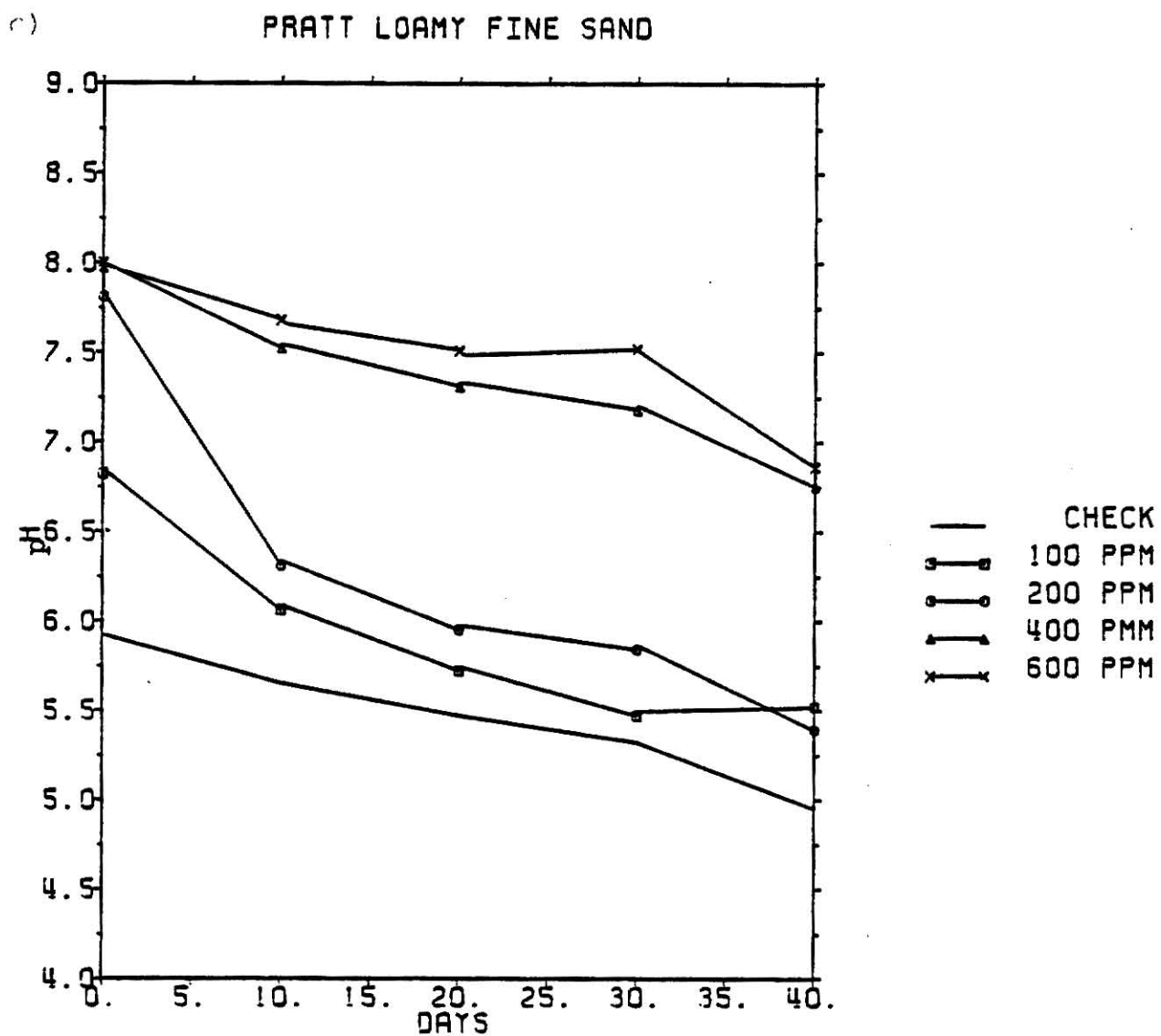
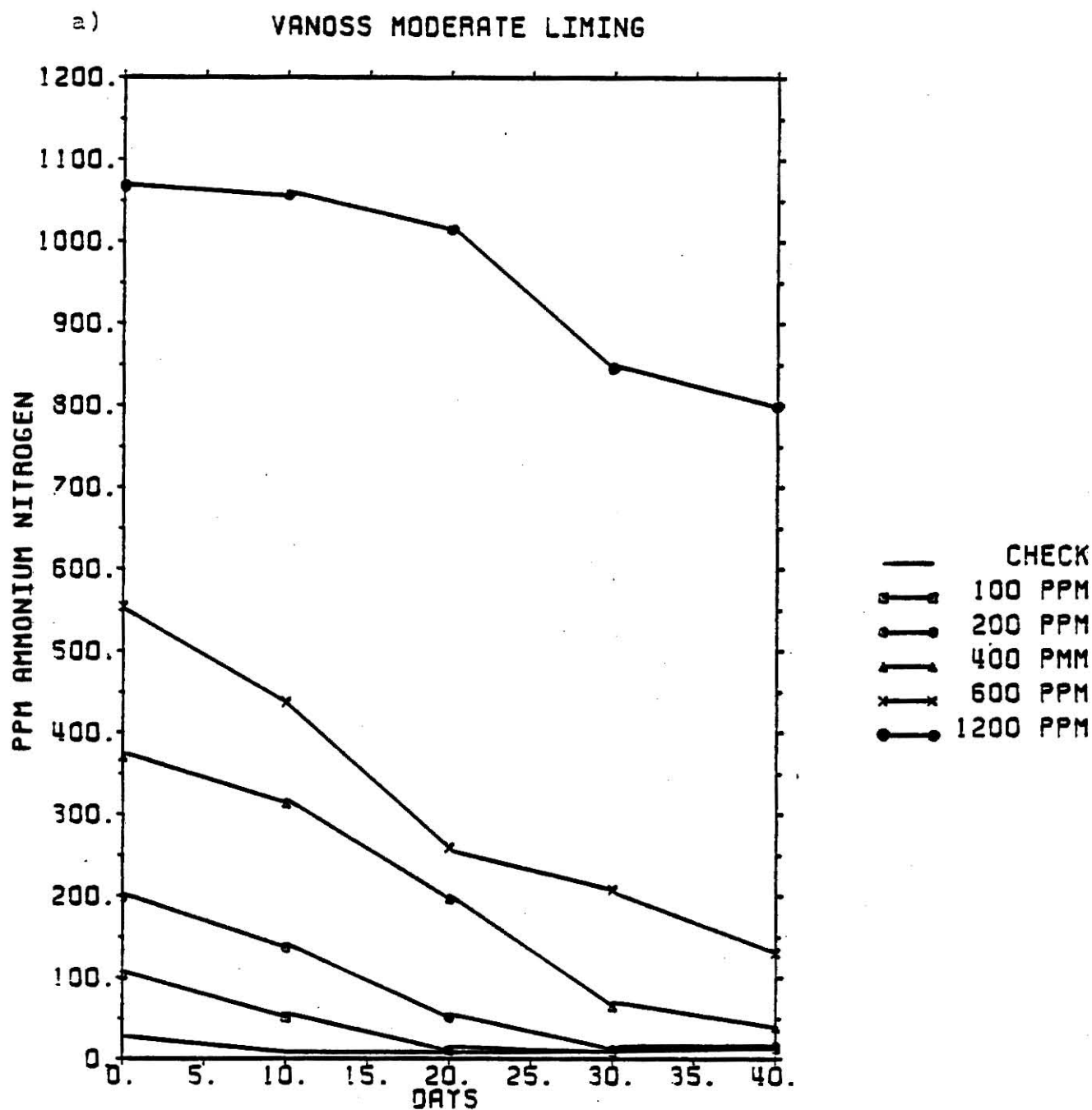
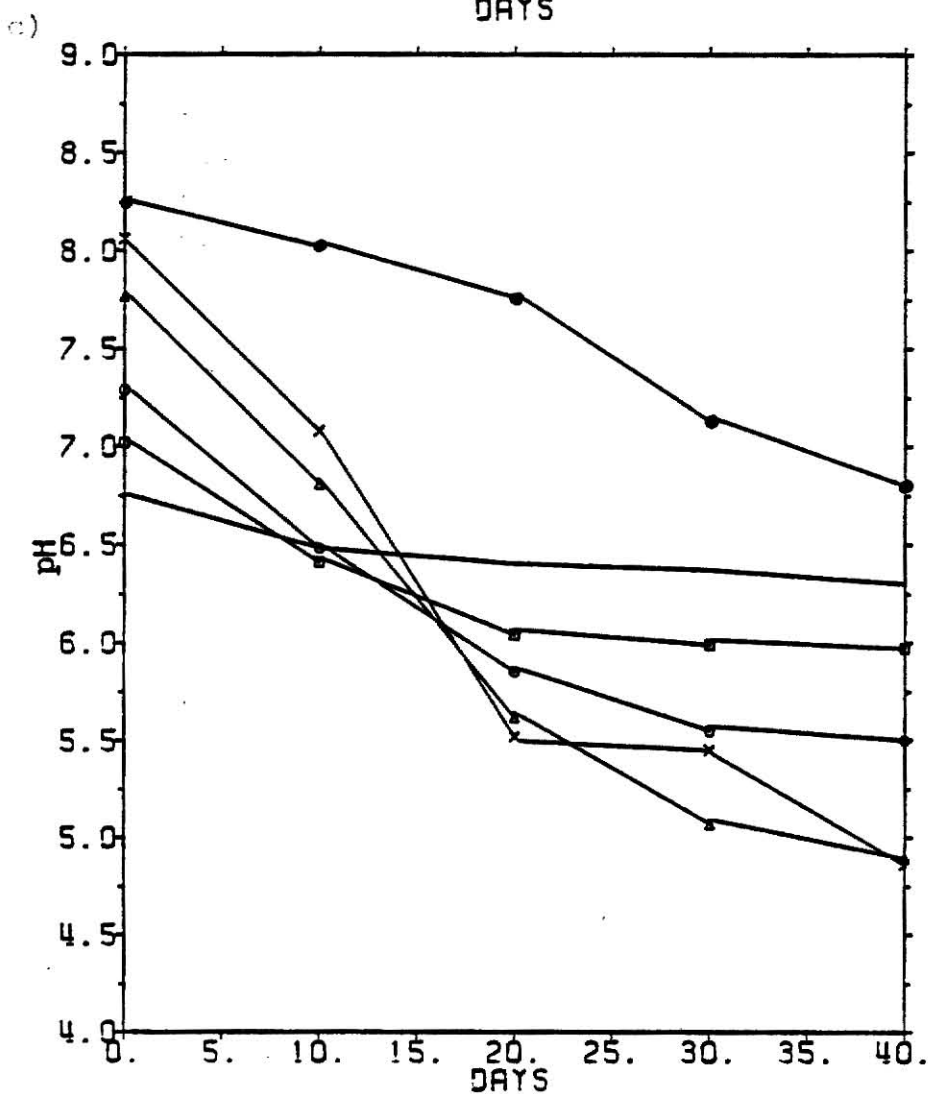
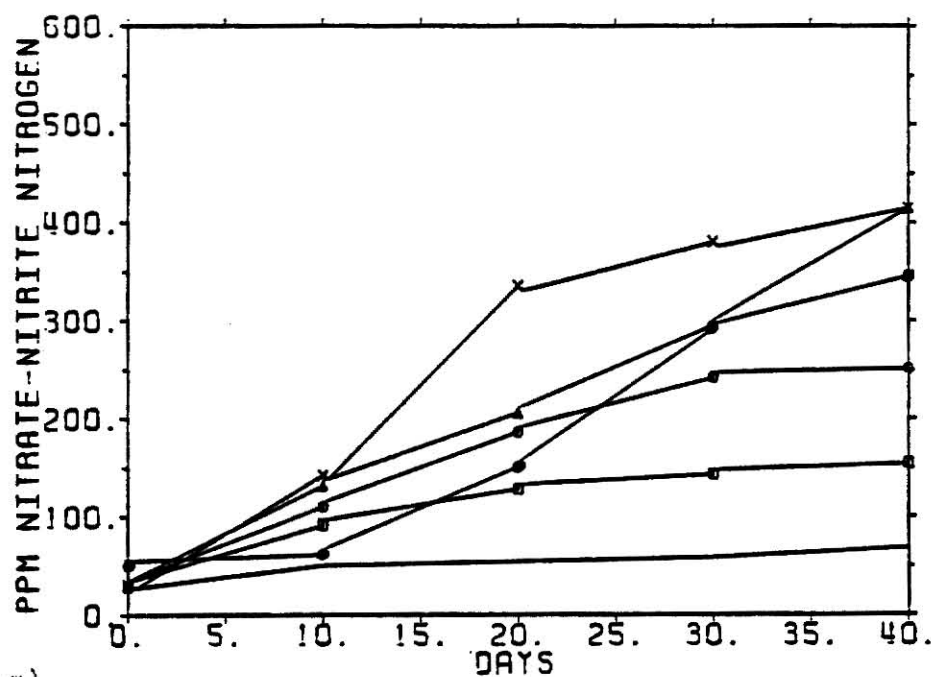


Figure 20. Nitrification Curves a) change in ammonium concentration over time, b) change in nitrite and nitrate concentration over time, and c) change in pH over time.



) VANOSS MODERATE LIMING



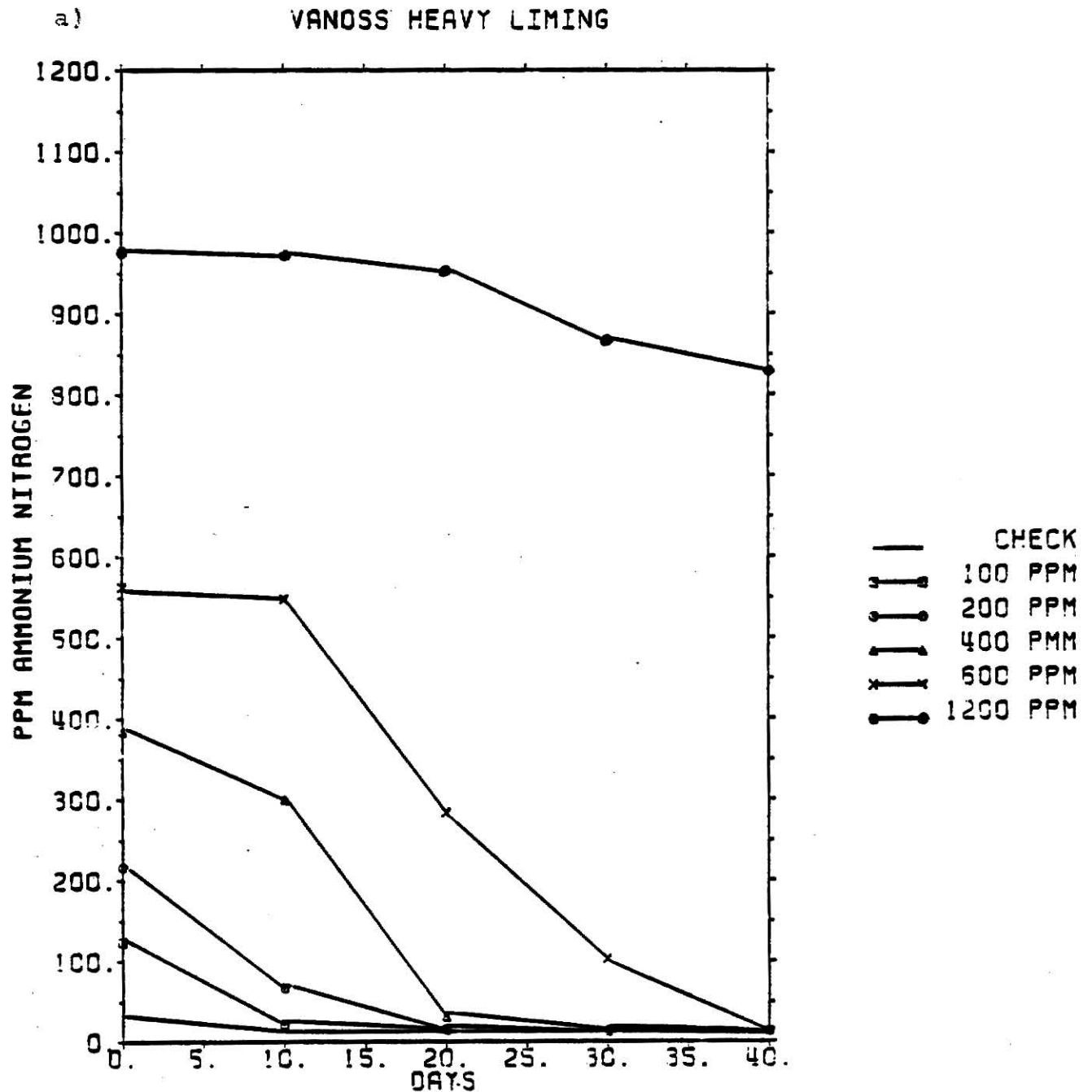
initial inhibition of nitrification compared to the other rates. For the heavy liming (Fig. 21b) inhibition of nitrification was seen initially in the three highest ammonia rates with inhibition greater as the rate increased. Inhibition lasted until a pH value somewhere below 8.5 was reached. This can also be seen in the Blanket soil at the 1200 ppm rate (Fig. 16b) where nitrification was slower than it was for the 600 ppm rate until the pH dropped from the initial level of 8.5. At the highest liming of the Vanoss soil the rates of 600 ppm nitrogen and below showed almost complete nitrification by 40 days.

Results from the Vanoss soils indicate that ammonia additions did not greatly raise the pH when the soil pH was already high due to liming. Where there was no nitrification inhibition and sufficient substrate, soil pH rather than substrate concentration appeared to control the rate of nitrification. For instance the 1200 ppm and 600 ppm nitrogen rates of the unamended Vanoss soil and the 600 ppm and 200 ppm nitrogen rates of the moderately Vanoss soil gave similar initial pH values and nitrification rates.

Addition of the $[Al(OH)^{+2}]_x$ polymers had a detrimental effect on nitrification in the Blanket soil (Fig. 22b). Leaving the soil at a pH below 5.0 must have greatly reduced the soil's nitrifying bacteria population.

The addition of aluminum hydroxide polymers to the Vanoss soil also reduced nitrification (Fig. 23b). Since most of the inhibition occurred in the first ten days, the soil's initial nitrifying bacteria population must have been quite small, causing an increase in the lag period. Later in the incubation the nitrification rates were not depressed by the amendment except for the 1200 ppm and 600 ppm ammonia

Figure 21 Nitrification Curves a) change in ammonium concentration over time, b) change in nitrite plus nitrate concentration over time, and c) change in pH over time.



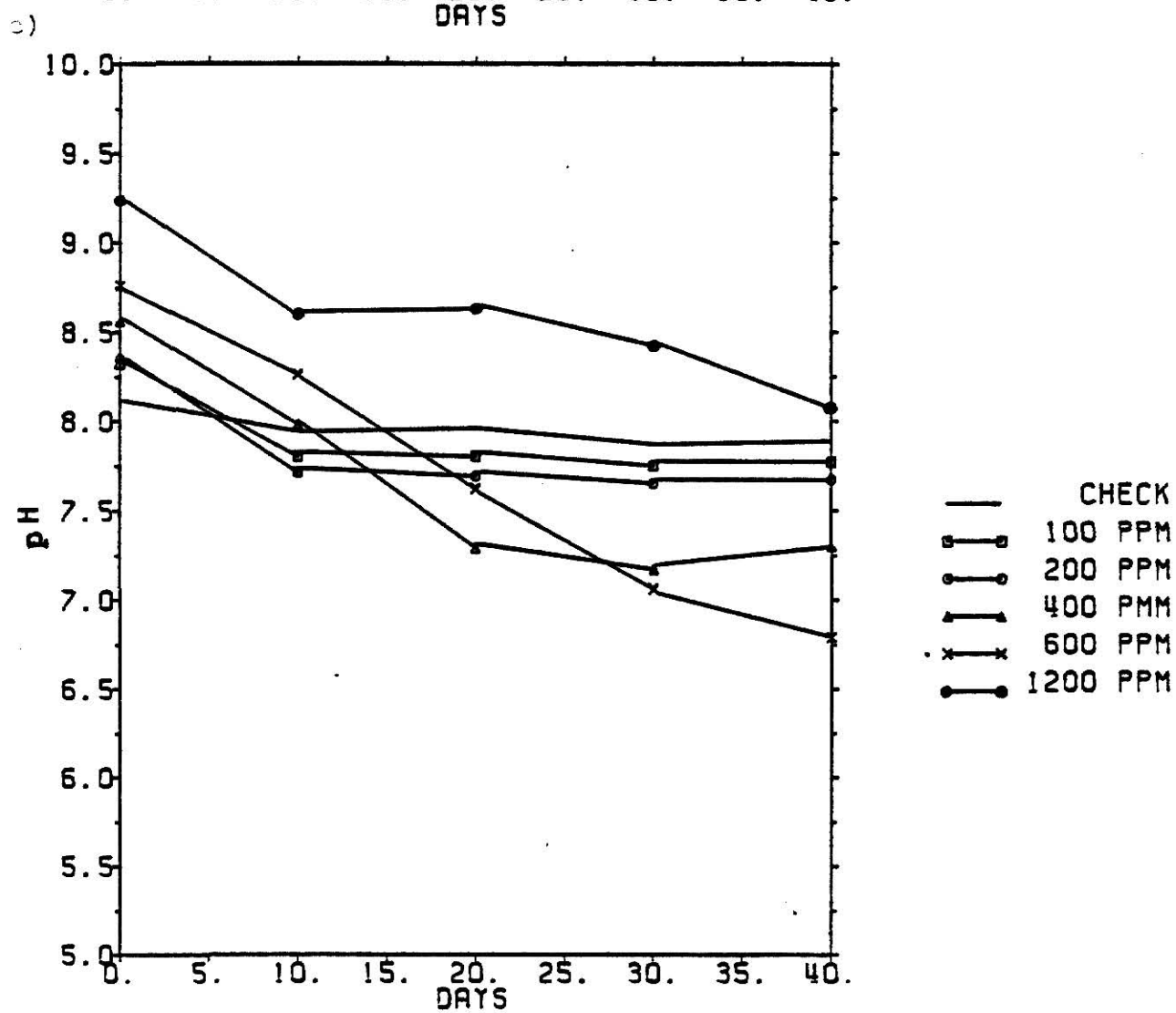
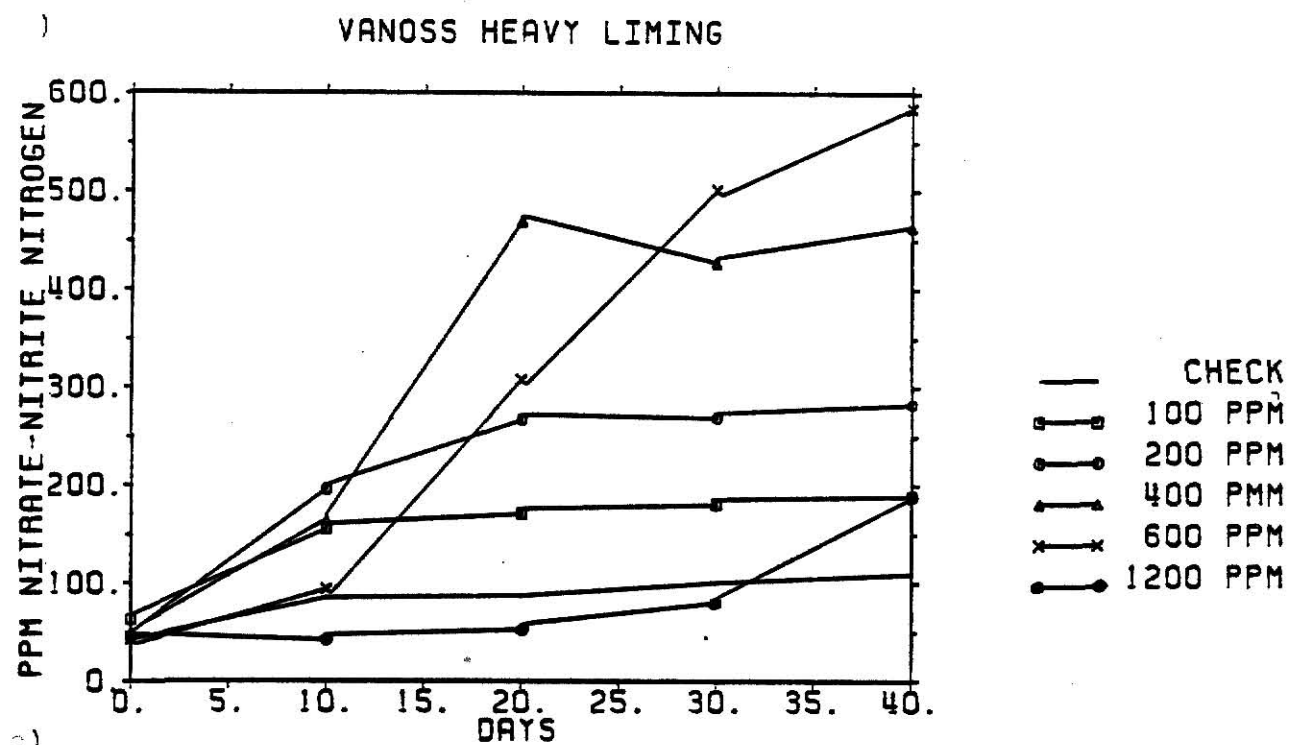
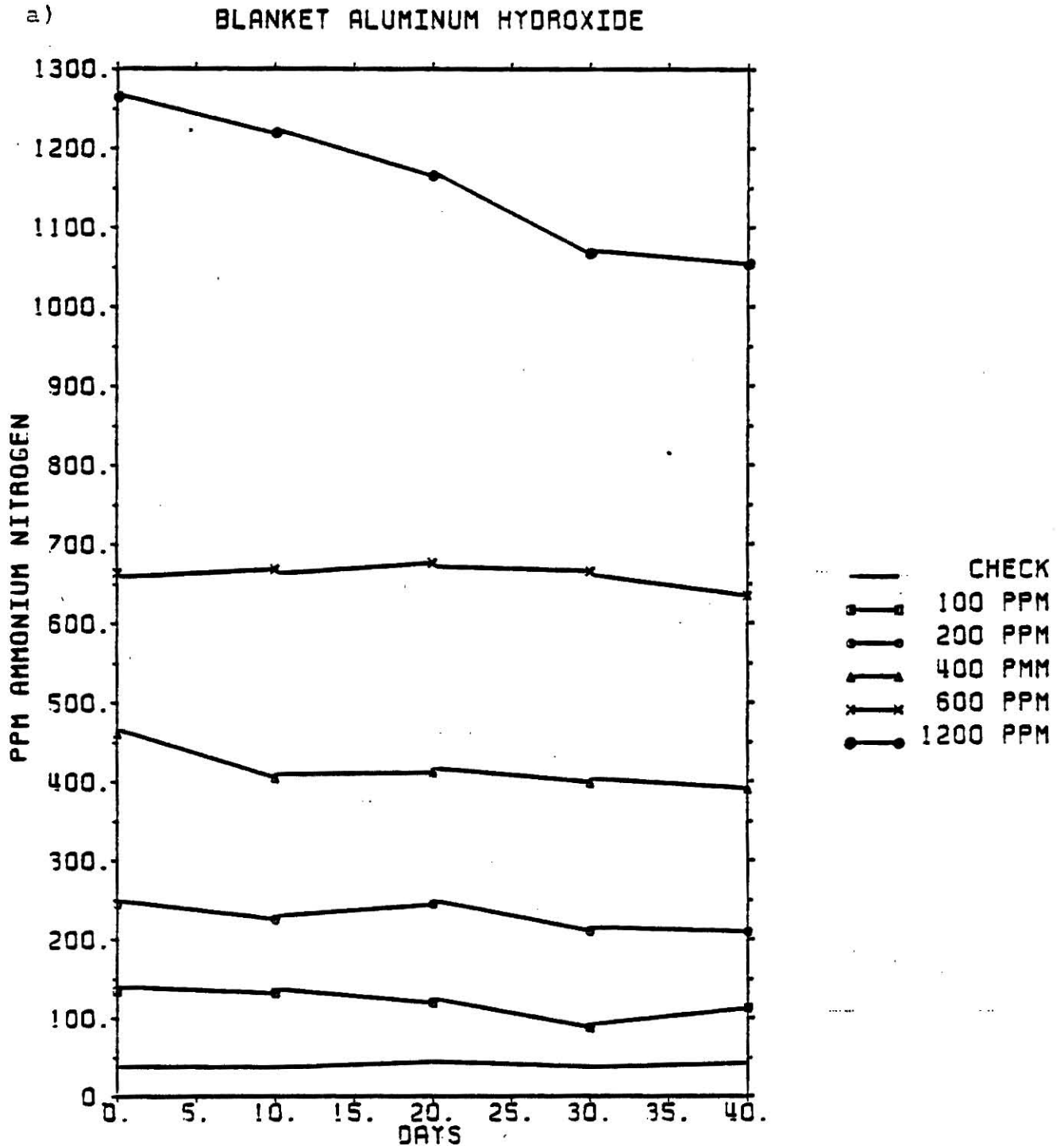


Figure 22 **Nitrification Curves** a) change in ammonium concentration over time, b) change in nitrite plus nitrate concentration over time, and c) change in pH over time.



BLANKET ALUMINUM HYDROXIDE

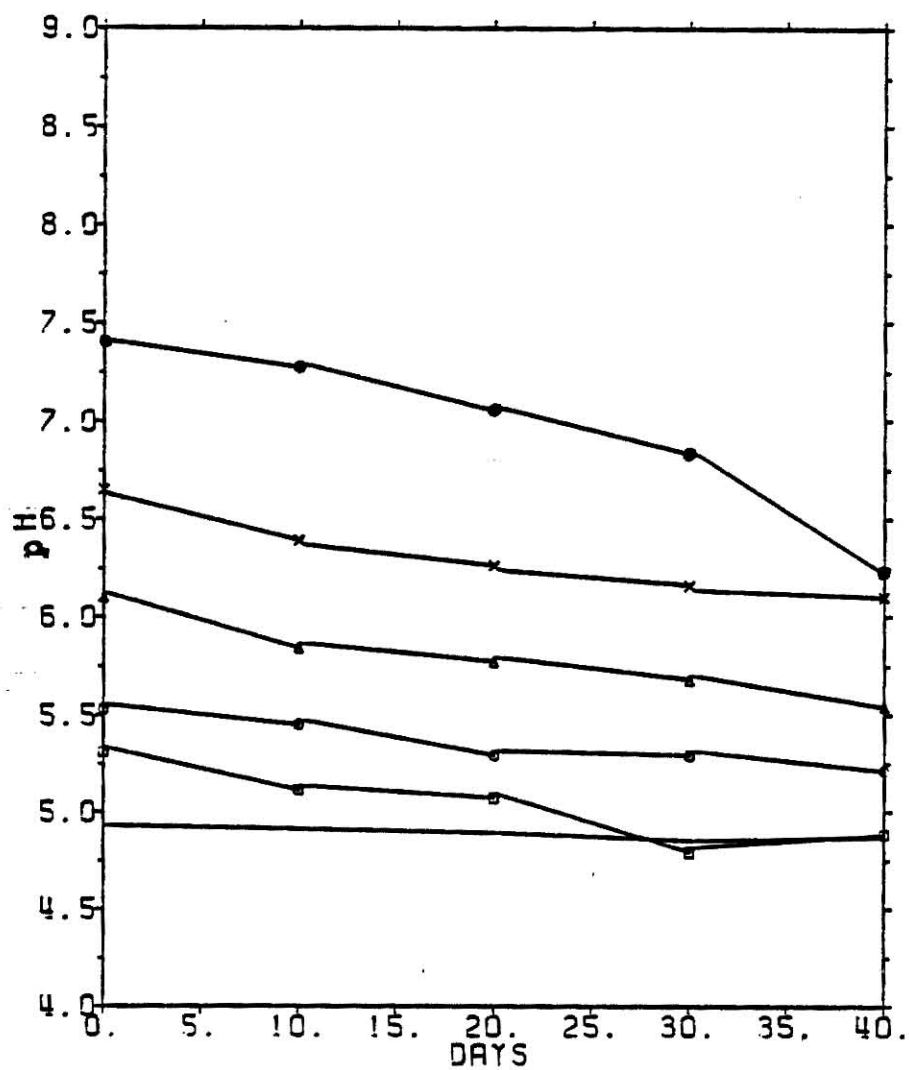
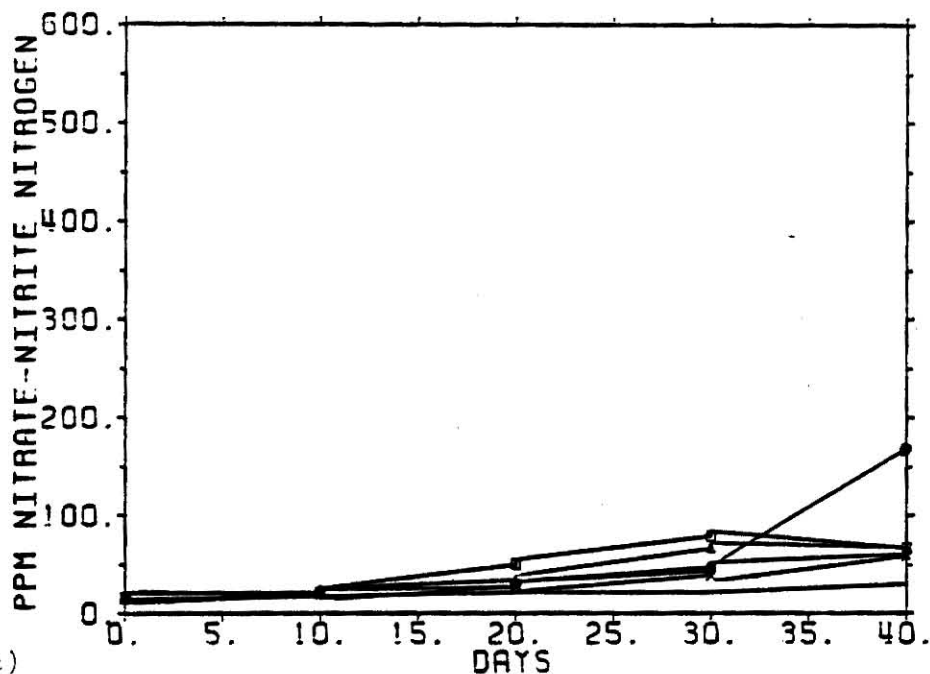
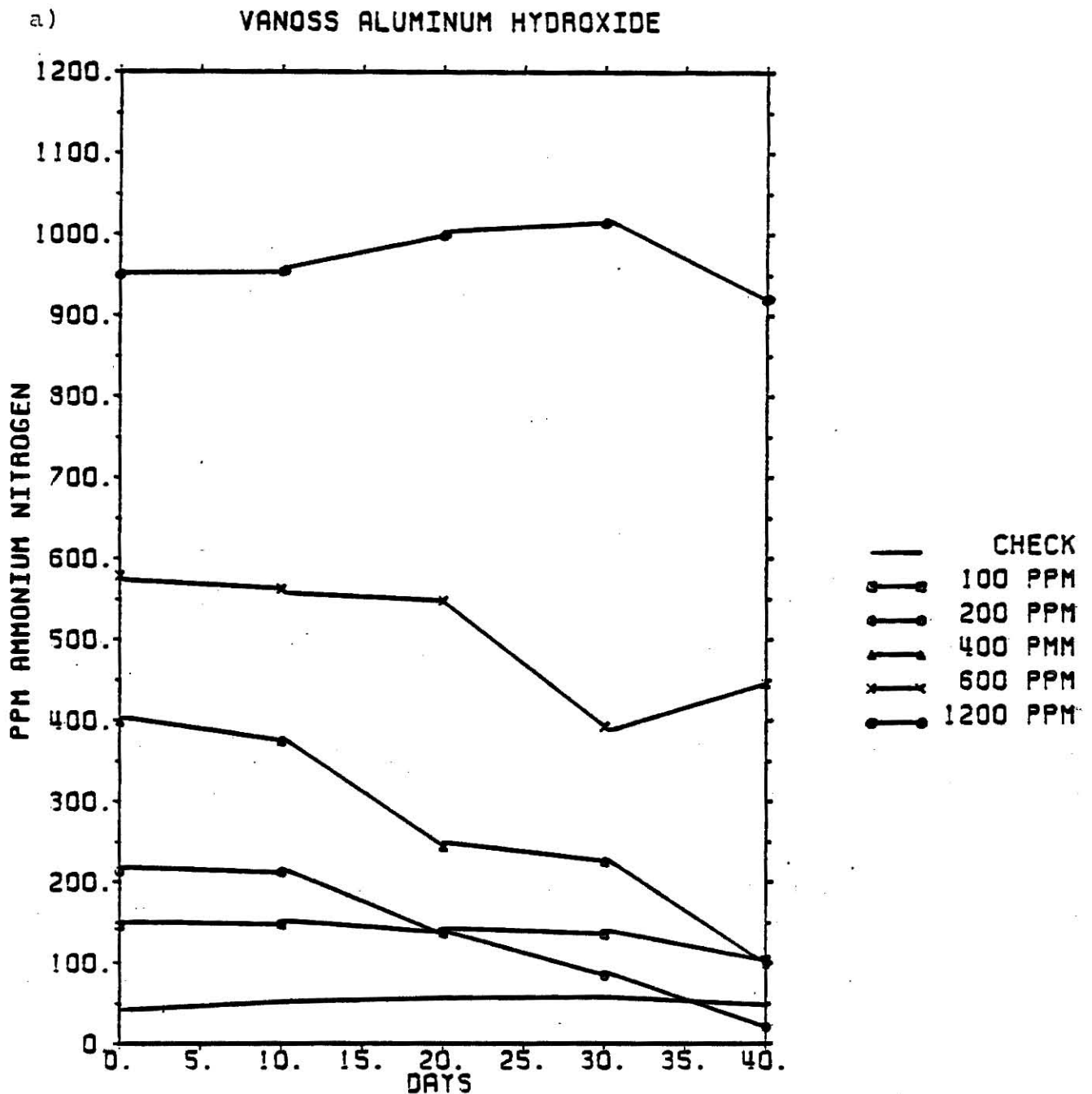
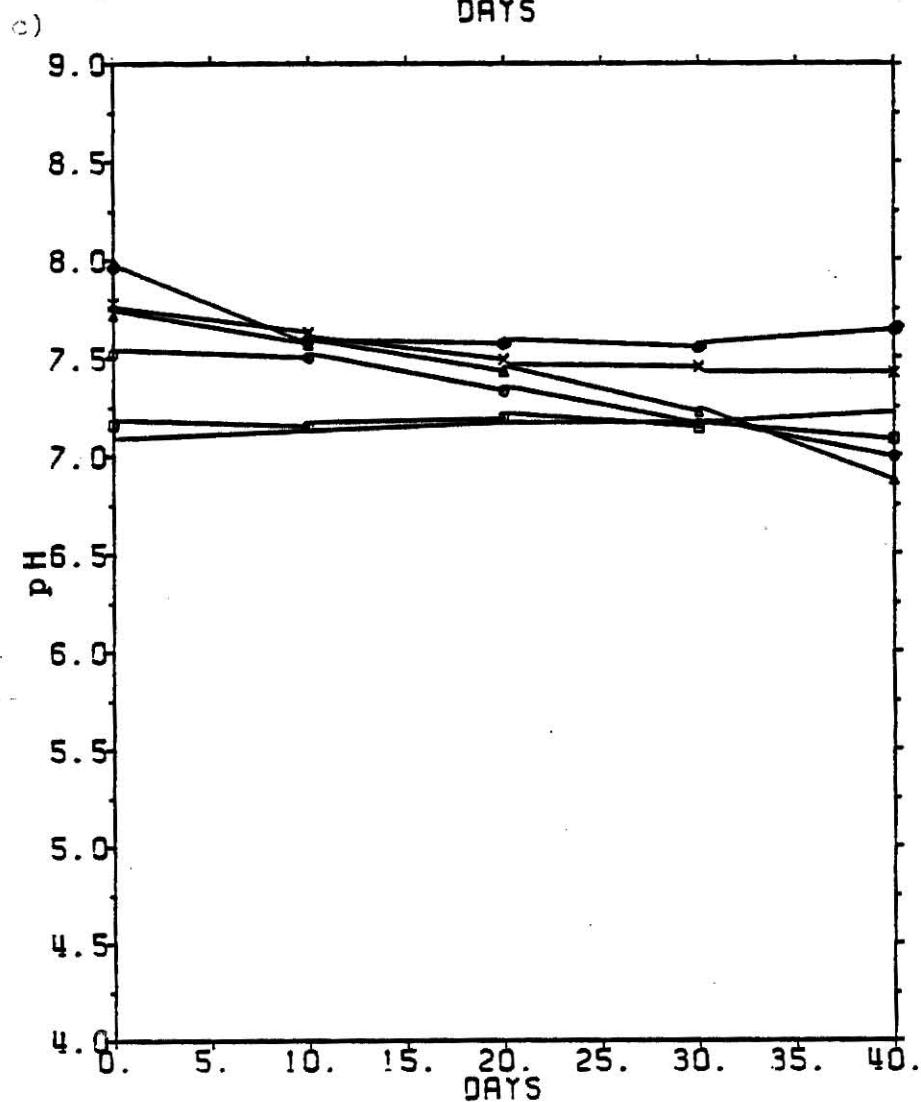
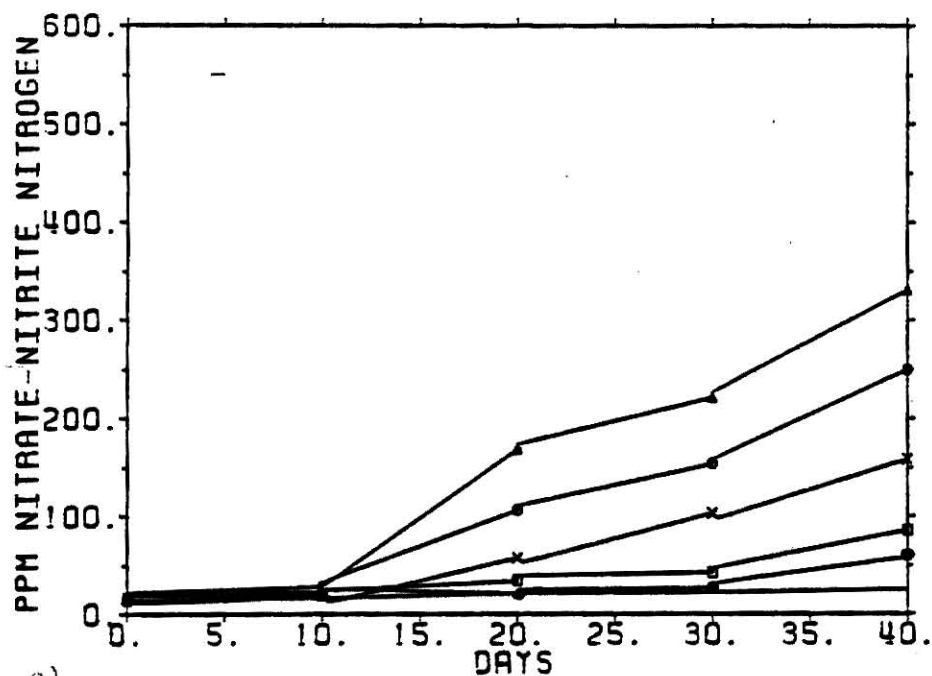


Figure 23 Nitrification Curves a) change in ammonium concentration over time, b) change in nitrite plus nitrate concentration over time, and c) change in pH over time.



VANOSS ALUMINUM HYDROXIDE



nitrogen rates which were greatly inhibited although the initial pH values were below 8.0. The cause of the slower nitrification for these two high rates in the aluminum hydroxide amended Vanoss soil will be discussed in the unionized ammonia level study.

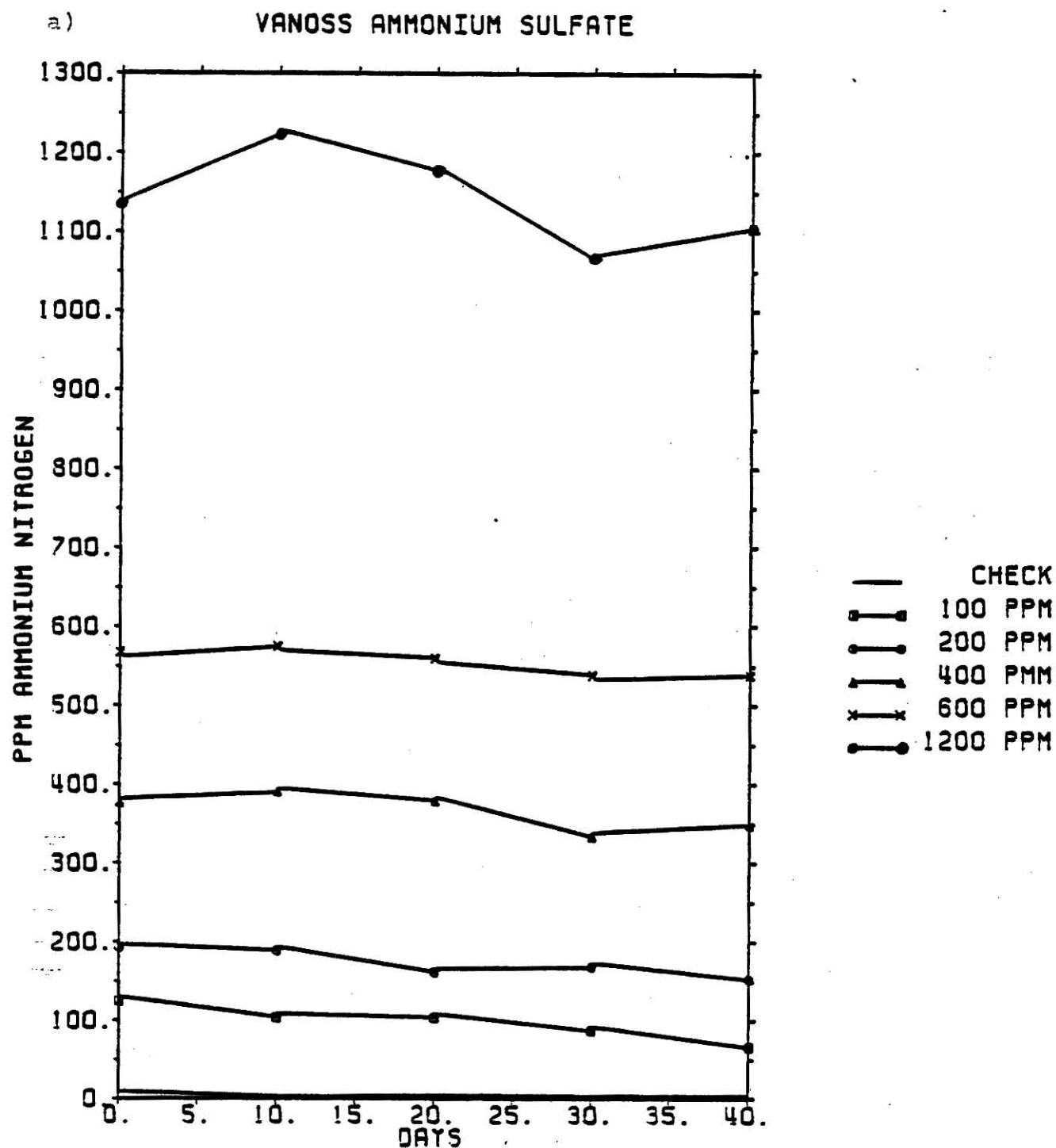
The ammonium sulfate was added to the Vanoss soil to test the effect of an initially acid fertilizer. At all rates the pH was initially reduced or reached toxic low pH levels (Fig. 24c). At pH values of 5.2 was the minimum pH at which nitrification occurred in the Vanoss soil.

The data from this study show that nitrification increases with pH until a maximum rate pH level is reached. For the silt loams used in this study this maximum rate pH level is between 7.5 and 8.5. Above this pH range inhibition rapidly increases. Raising the soil's pH to this level or higher is controlled by the amount of added ammonia and the soil's buffering capacity to approximately pH 8.5.

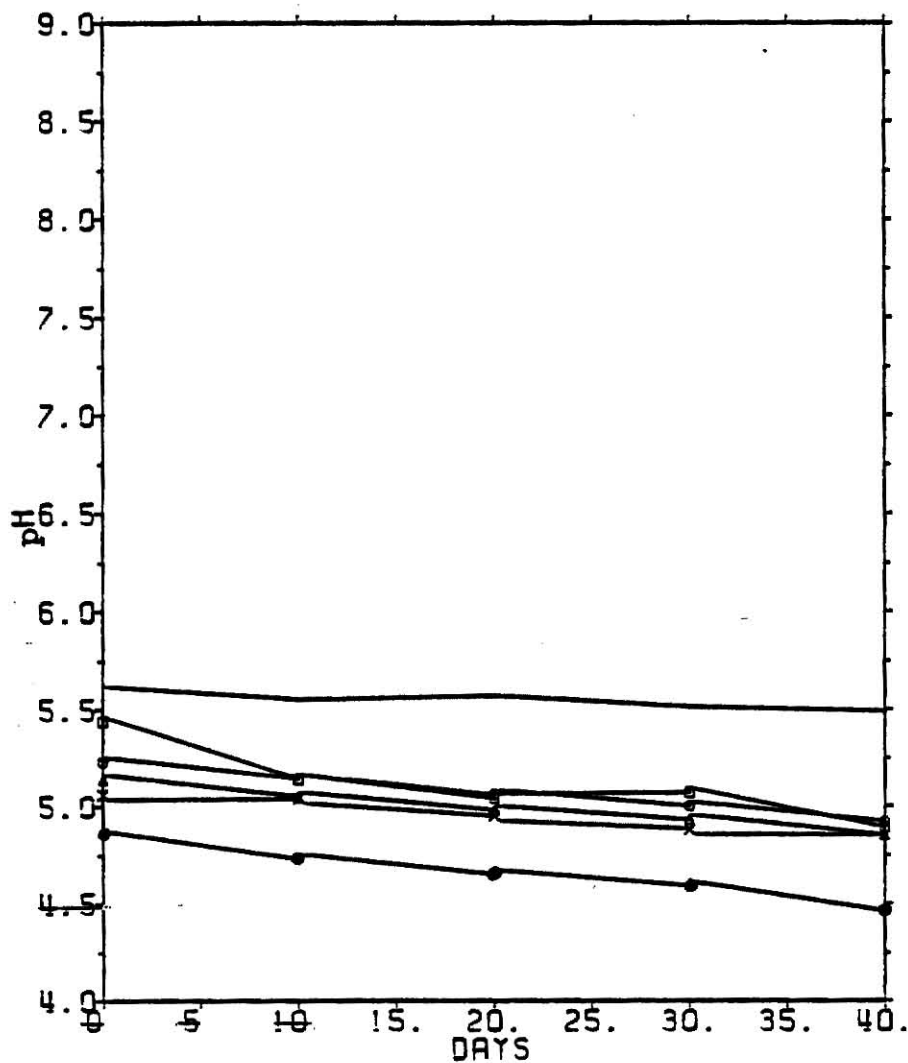
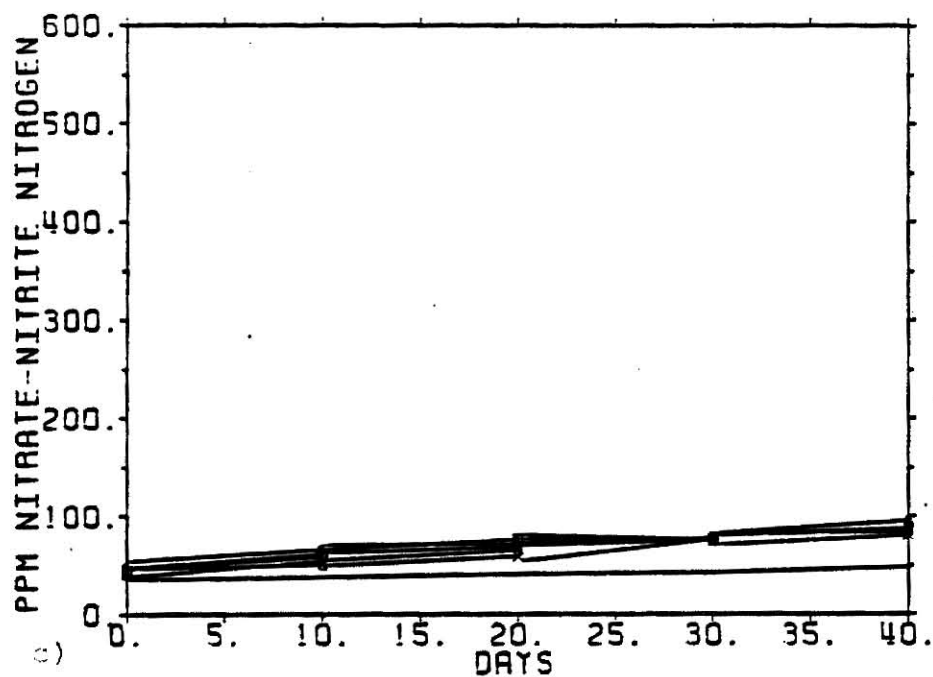
The optimum pH range reported above is higher than what has been reported by other researchers (Meyers, 1974) as being the optimum range for nitrification.

A general relationship was found between nitrification rates and pH for the soils studied. This relationship was best expressed at the 1200 ppm ammonia nitrogen rate for the silt loams and limed silt loams. A plot of ppm nitrate plus nitrite nitrogen increase per ten days as a function of pH at the start of each period is shown in Figure 25. Data points were connected according to a soil's initial pH value to its succeeding pH values over the time periods. All points where no nitrates plus nitrite increase occurred were omitted.

Figure 24 Nitrification Curves a) change in ammonium concentration over time, b) change in nitrite plus nitrate concentration over time, and c) change in pH over time.



VANOSS AMMONIUM SULFATE



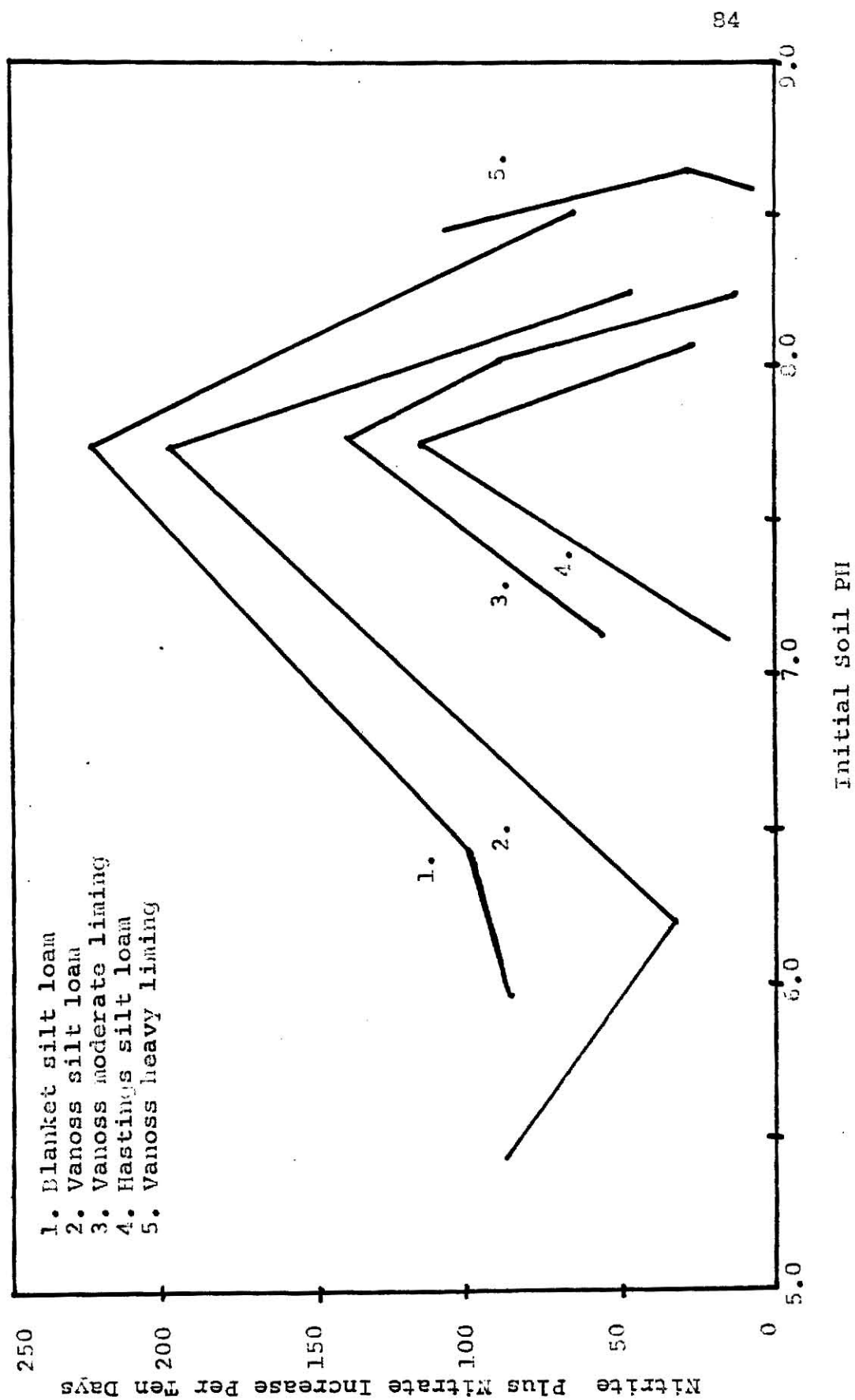
Nitrification was assumed to follow zero order kinetics for all points plotted since substrate concentration was always much larger than the rates of nitrification (Wong-Chong and Loeher, 1978). Data points on the right side of Fig.(25) correspond to data from the initial time periods and would be in the lag phase for nitrification. At these time periods the nitrification enzyme concentration would be reduced which would in turn slow the nitrification rate. But high pH conditions would also cause a decrease in the nitrification rate in the high pH range. This relationship can be seen in the Vanoss heavy liming which had enough time to overcome the lag period yet still had low nitrification rates.

If it is assumed that once a soil no longer increases its nitrification rate with time it is no longer in the lag phase, then Fig.(25) would show that all data points below pH 7.8 would be in the maximum rate phase for nitrification. If this is true then Fig. (25) shows that the optimum pH for the maximum rate of nitrification for these soils is above neutrality and close to pH 7.75 as was observed before.

No clear relationship of nitrification rate as influenced by pH was found for the lower rates of added ammonia. Data from the lower showed that the lag period was overcome when lower pH values were obtained by the various soils. This did not allow comparison between the different soils because the pH range of each soil in its maximum rate phase varied between the soils. Comparisons between the high rate and the lower rates of added ammonia for each soil was not possible also for this reason.

Increasing the buffering capacity helps maintain a constant pH during nitrification whether the pH is optimum or inhibitory. In the

Figure 25 Nitrification rates of five soils versus their initial soil pH.



aluminum hydroxide amended soils the optimum pH values did not initially nitrify as well as the unamended soils. This was possibly due to the initial effect of the amendment on the nitrifying bacteria population. A reduction in the nitrifying bacteria would cause an increase in the lag period while the population increased to its maximum level possible in the soil after addition of substrate.

The soils amended with aluminum hydroxide did maintain their pH levels above sub-optimum levels better than the unamended soils and if allowed to nitrify to completion would probably have achieved greater total nitrification than the unamended soils for the high ammonia rates.

In the Pratt soil, which had a very low buffering capacity and cation exchange capacity, had its pH raised to inhibitory levels by low amounts of added ammonia. The resulting pH's were similar to those obtained by adding high levels of ammonia to the heavier textured soils. In this case addition of the higher levels of ammonia to the Pratt soil would have a similar effect on nitrification regardless of the initial pH of the soil since the final pH obtained would be similar in all cases.

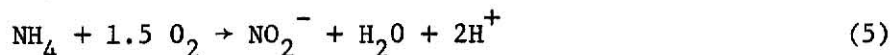
From this study it becomes evident that in understanding and predicting nitrification rates it is important to know the pH level throughout the entire process. In order to predict pH levels during nitrification not only must the soil's initial pH be known but also its buffering capacity. Several other factors would need to be considered in a nitrification model. Included in these factors would be the effect of pH on the nitrification rates and the soil's cation exchange capacity for ammonia adsorption.

N Source Acidity Study

In calculating the acidity produced by nitrification of three sources of ammonium, this study makes several assumptions. The first assumption is that any change in pH during incubation is caused by nitrification only. Another assumption is that acid production can be quantitatively measured using a pH buffer curve for this Blanket silt loam as shown in Figure (26).

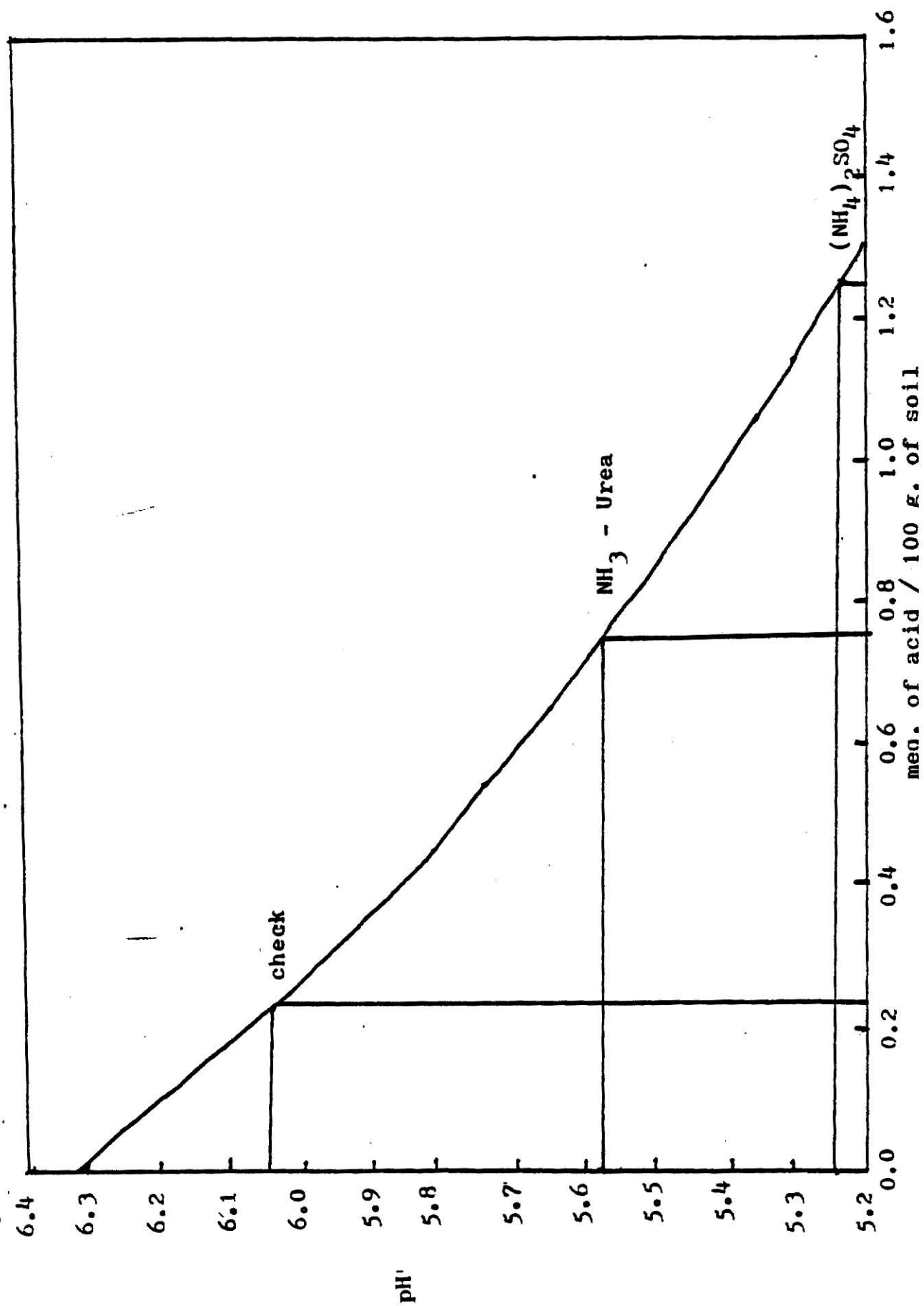
In calculating the meq. of nitrogen nitrified and the meq. of H^+ produced by the three ammonia sources, the base levels used were the pH and the nitrate concentration of the check at the end of 40 days incubation. This procedure involves the assumptions that in all soil treatments the same amount of residual ammonium was nitrified as in the check treatment and that the same amount of H^+ was produced by the residual nitrification in all treatments. Any reduction in pH and any increase in nitrate level over the check treatment at the final sampling date was considered to accurately describe the total effect of the added ammonium sources for this study's calculations. If the check values were not subtracted from the other treatment values in the calculations the values of meq. H^+ /meq. N nitrified obtained would be 0.73, 0.72, and 1.16 for NH_3 , Urea, and $(NH_4)_2SO_4$ respectively.

Nitrification of the aqua ammonia and urea would involve the following reactions:



From these reactions it can be seen that one OH^- and 2 H^+ or one H^+ in excess is produced for each ammonium molecule oxidized. Nitrification

Figure 26 pH change during addition of acidity to the Blanket silt loam.



of $(\text{NH}_4)_2\text{SO}_4$ would involve only reaction (5) since the nitrogen is added already in the ammonium form. Therefore two molecules of H^+ would be produced for each molecule of ammonium oxidized.

Other soil pH reactions may have affected the values of meq. of H^+ /meq. of N nitrified. Besides this there were several other problems in the experimental design. The ammonium concentration curves (Fig. 27a) indicate that all the extractable ammonium from all three sources was nitrified after 30 days although nitrate levels still increased until 40 days. However, some of the added ammonium may have been fixed by the clay and/or organic matter in the soil and later released for nitrification.

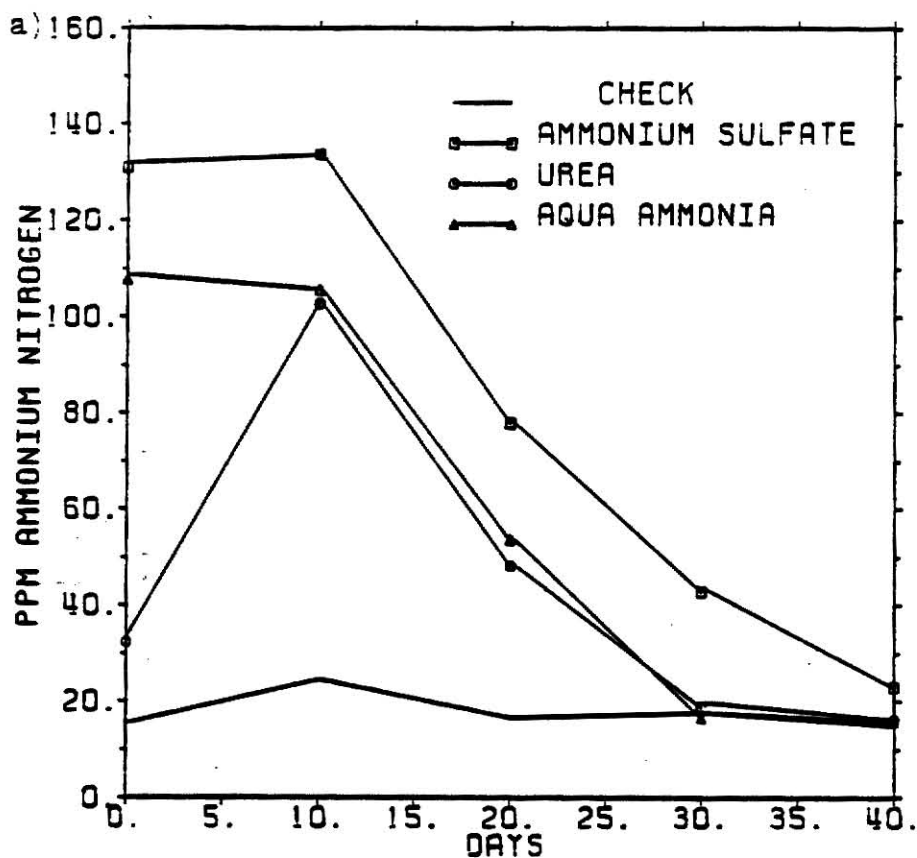
Nitrate levels (Fig. 27b) would suggest that nitrification of $(\text{NH}_4)_2\text{SO}_4$ was affected as the pH initially reached approximately 5.1. Also the ammonium sulfate shows an initial pH decreases not explained by reactions (4) or (5) due to the acid nature of $(\text{NH}_4)_2\text{SO}_4$ in solution. Although this effect may be reduced after nitrification is complete. For some reason though the values of acidity produced per amount of nitrogen nitrified were lower than expected (Table 9).

Determining acidity production by nitrification in soil will always involve difficulties but this study did show important relationships. One relationship is the similarity of the aqua ammonia and the urea in the pH curves and the final amount of acidity produced. A second relationship is the almost twofold increase in acidity production by the ammonium sulfate. These relationships support the theoretical reactions (4) and (5) which are not always fully understood by those concerned with the use of these fertilizers and their effects on soil pH.

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Figure 27 Nitrification of three ammonium sources a) change in ammonium concentration, b) change in nitrite plus nitrate concentration, and c) change in pH over time.



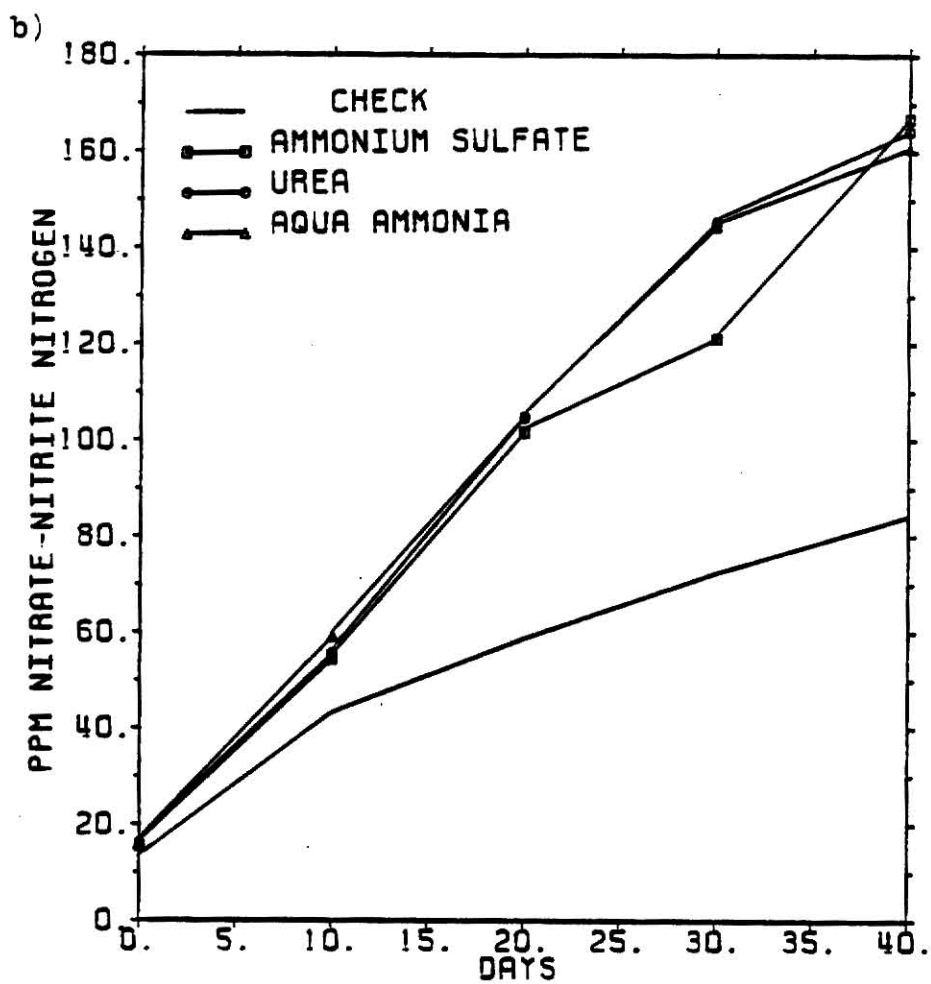


Figure 27 cont.

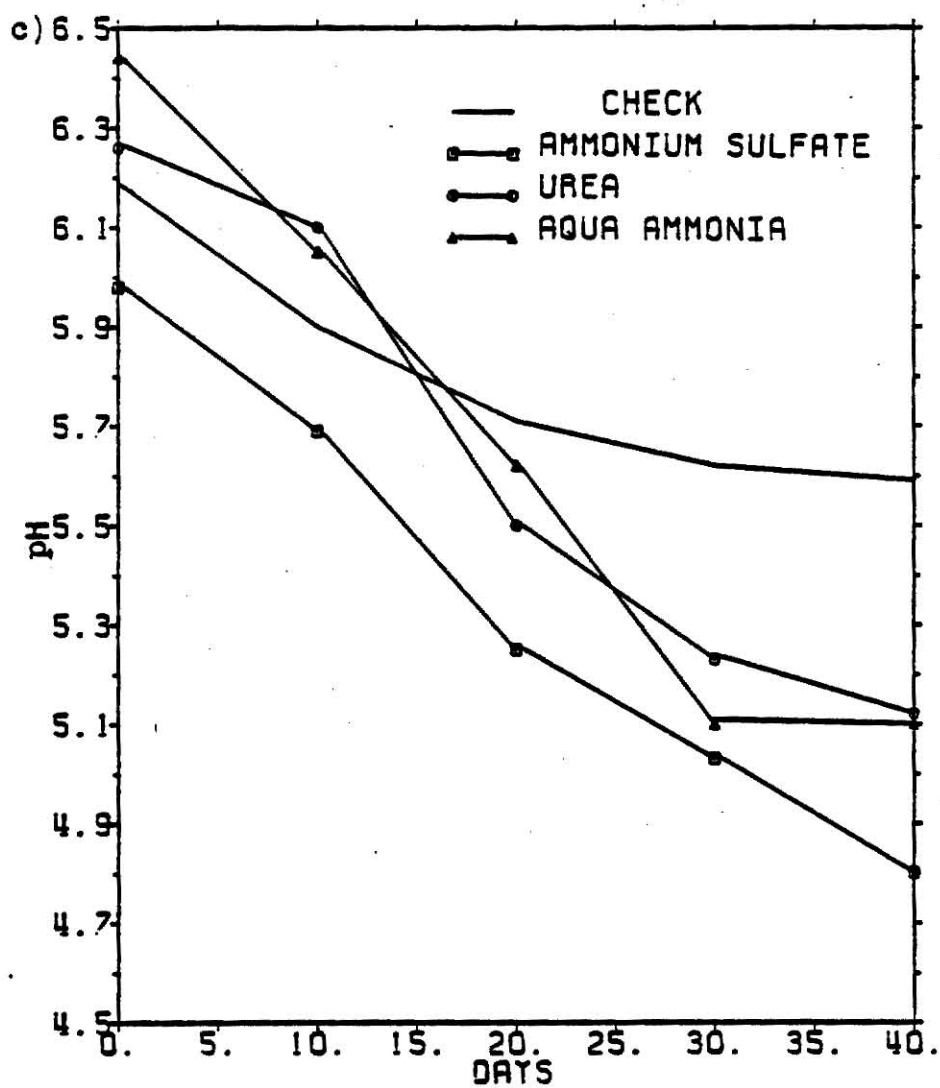


Table 9 Production of Acidity by Nitrification of Three Ammonium Sources

		Days			
		0	10	20	30
check	$\text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-$ pH	15.5 13.5 6.19	24.5 43.3 5.90	16.6 58.8 5.71	17.7 72.4 5.62
NH_3	$\text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-$ pH	107.8 16.1 6.44	105.6 59.1 6.05	53.6 104.9 5.62	16.6 144.4 5.10
$(\text{NH}_4)_2\text{SO}_4$	$\text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-$ pH	131.0 15.5 5.98	133.7 54.4 5.69	77.9 101.5 5.25	42.8 121.1 5.03
Urea	$\text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-$ pH	32.3 16.1 6.26	102.8 55.5 6.10	48.2 104.7 5.50	18.8 145.3 5.23
$\hat{\sigma}$	$\text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-$ pH	3.1 0.9 0.07	4.0 3.2 0.10	3.5 6.2 0.08	4.3 0.8 0.07

Table 9 continued

	pH (1:7)	Meq. H^+ 100 g soil	meq. N (nitrified) 100 g soil	meq. N (minus check) 100 g soil	meq. H^+ meq. N
CHECK	6.05	0.25	0.51	-----	0.49
NH_3	5.58	0.51	1.06	0.55	0.93
Urea	5.58	0.51	1.08	0.57	0.89
$(NH_4)_2SO_4$	5.24	1.00	1.10	0.59	1.69

Maximum pH Study

The last nitrification study was conducted at three low rates of added ammonia where it was expected free ammonia levels would not become toxic until very high pH levels were reached. If free ammonia levels would not become toxic below the absolute maximum pH for nitrification then all three rates should show similar pH versus nitrification relationship and this maximum pH should be determinable.

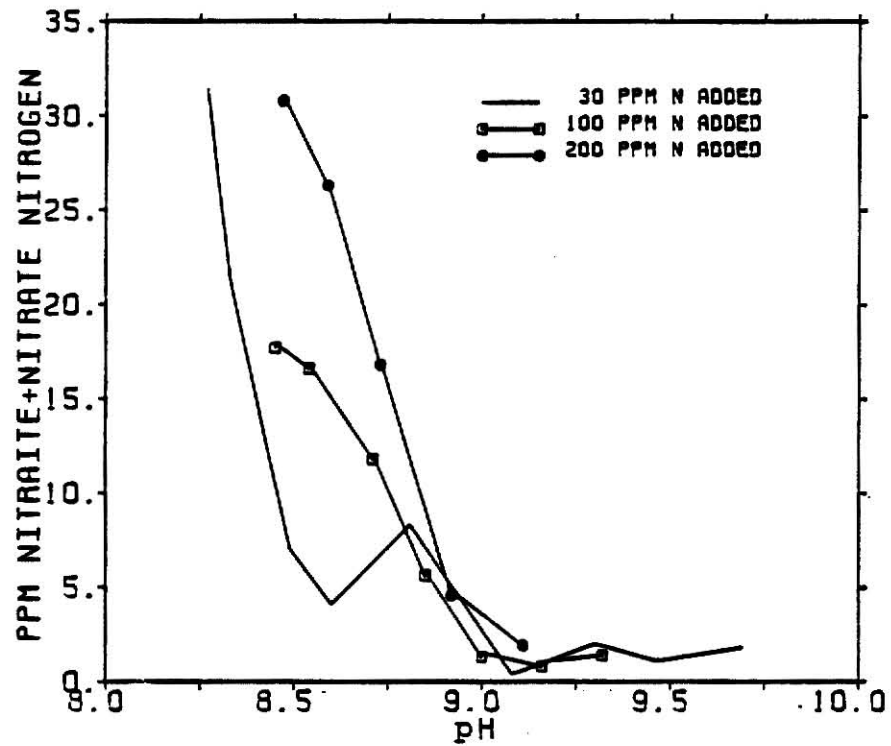
Inhibition of nitrification began around pH 8.5 and reached maximum inhibition around pH 9.0 (Fig. 28). The reason that the curves were not exactly the same may be due to nitrification rates being dependent on substrate concentration of ammonium at low ammonium concentrations (Misra et al., 1974).

In the graph of the second step of nitrification (nitrite to nitrate) the 200 ppm rate fell below the 100 ppm rate (Fig. 28b). High nitrite accumulations are shown in Table (12) for treatments two through four, indicating free ammonia was being toxic to Nitrobacter sp. In the experiment described after this one, it was shown that the 200 ppm nitrogen rate did reach free ammonia levels considered toxic before a pH of 9.0 was reached (Smith, 1964).

Very little CaO was added (0.16% by weight) to the soils in treatment 1 (Tables 10-12). In treatment 1 the two higher nitrogen rates showed greater nitrification at a slightly alkaline pH but the lower rate which began near neutrality showed a lower nitrification rate than the same rate at higher pH values. It appears that nitrification was favored by slight alkalinity in this soil, and a nitrification curve would show maximum nitrification at this pH of slight alkalinity.

Figures 23 Maximum pH Study a) change in concentration of nitrite plus nitrate, b) change in nitrate concentration.

a)



b)

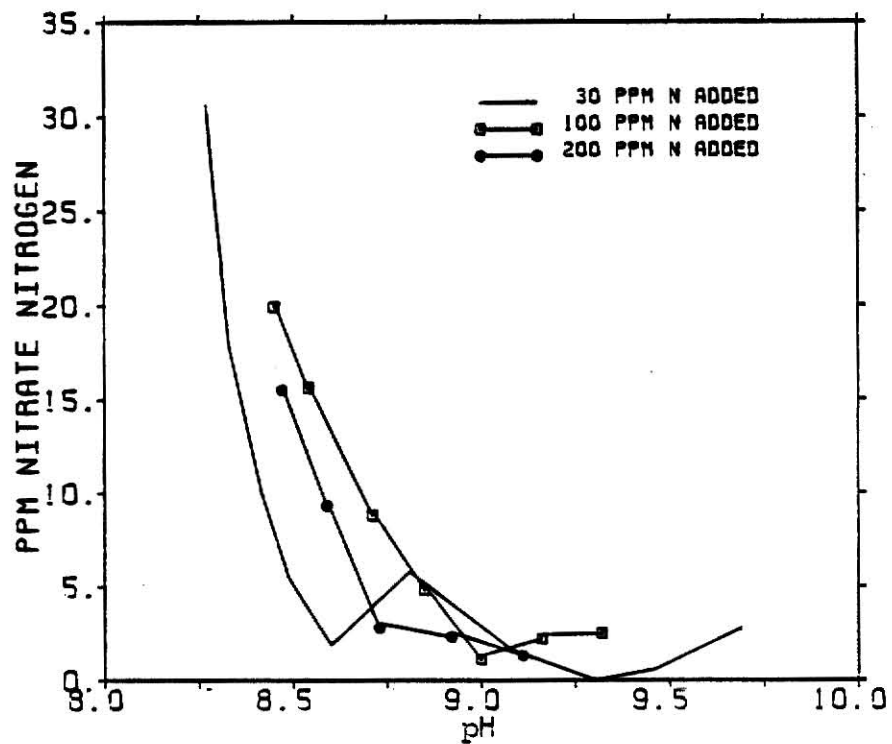


Table 10 Change in pH, ammonium, nitrite, and nitrate concentrations after one week of nitrification - 30 ppm added ammoniacal nitrogen.

Trt	CaO mgm/g	pH		NH_4^+		NO_2^-		NO_3^-		
		Initial	final	Initial	final	Initial	final	Initial	final	
1	1.6	7.17	6.22	39.4	26.5	0.0	0.1	70.8	86.3	
2	4.8	8.27	8.26	62.2	50.8	0.9	1.7	37.9	68.5	
3	6.4	8.33	8.38	61.5	60.8	0.8	4.3	33.9	51.7	
4	8.0	8.42	8.47	60.9	76.3	1.8	5.4	33.6	43.3	
5	9.6	8.49	8.52	59.6	82.6	1.2	2.8	30.4	35.8	
6	11.2	8.60	8.58	54.6	86.5	0.9	3.1	30.5	32.4	
7	12.8	8.81	8.46	60.9	77.4	1.6	4.1	27.7	33.5	
8	14.4	9.08	8.54	58.8	78.6	2.3	1.1	29.6	31.2	
9	16.0	9.30	8.61	57.7	73.3	0.0	2.0	30.0	30.0	
10	17.6	9.46	8.76	55.5	63.8	1.0	1.5	29.0	29.6	
11	19.2	9.69	8.85	55.9	53.8	1.5	0.5	28.8	31.6	
$\bar{\sigma}$		0.04	0.03	3.01	3.68	0.93	1.65	1.91	2.78	

Trt	ΔpH		ΔNH_4^+		ΔNO_2^-		ΔNO_3^-		$\Delta (\text{NO}_2^- + \text{NO}_3^-)$	
1	-0.95	-12.9	0.1	15.5	15.6					
2	-0.01	-0.7	0.8	30.6	31.4					
3	0.05	15.4	3.5	17.8	21.3					
4	0.05	23.0	3.6	9.7	13.3					
5	0.03	31.9	1.6	5.4	7.0					
6	-0.02	16.5	2.2	1.9	4.1					
7	-0.35	19.8	2.5	5.8	8.3					
8	-0.54	15.6	-1.2	1.6	0.4					
9	-0.71	8.3	2.0	0.0	2.0					
10	-0.70	-2.1	0.5	0.6	1.1					

Table 11 Change in pH, ammonium, nitrite, and nitrate concentrations after one week of nitrification - 100 ppm added ammoniacal nitrogen.

Trt	CaO mgm/g	pH		NH ₄ ⁺		NO ₂ ⁻		NO ₃ ⁻	
		initial	final	initial	final	initial	final	initial	final
1	1.6	7.57	6.94	106.5	97.6	1.4	0.5	67.5	94.8
2	6.4	8.45	8.40	129.6	129.5	2.7	0.5	60.5	80.4
3	8.0	8.54	8.43	135.7	138.6	1.5	2.5	62.3	77.9
4	9.6	8.71	8.47	120.5	129.7	0.2	3.2	30.5	39.3
5	11.2	8.85	8.53	123.4	142.7	1.3	2.1	29.6	34.4
6	12.8	9.00	8.61	112.1	146.6	0.0	0.2	30.6	31.7
7	14.4	9.16	8.67	112.5	141.9	1.7	0.3	28.9	31.1
8	16.0	9.32	8.83	110.7	122.3	1.1	0.0	29.3	31.8
$\bar{\sigma}$		0.03	0.04	5.03	4.50	1.33	1.41	2.47	3.94

Trt	Δ pH	Δ NH ₄ ⁺	Δ NO ₂	Δ NO ₃	Δ (NO ₂ + NO ₃)
1	-0.63	-8.9	-0.9	27.3	26.4
2	-0.05	-0.1	-2.2	19.9	17.7
3	-0.11	2.9	1.0	15.6	16.6
4	-0.24	9.2	3.0	8.8	11.8
5	-0.32	19.3	0.8	4.8	5.6
6	-0.39	34.5	0.2	1.2	1.3
7	-0.49	29.4	-1.4	2.2	0.8
8	-0.49	11.4	-1.1	2.5	1.4

Table 12 Change in pH, ammonium, nitrite, and nitrate concentrations after one week of nitrification - 200 ppm added ammoniacal nitrogen.

Trt	CaO mgm/g	pH		NH ₄ ⁺		NO ₂ ⁻		NO ₃ ⁻	
		initial	final	initial	final	initial	final	initial	final
1	1.6	7.87	7.24	188.7	160.5	0.0	2.0	68.5	91.4
2	6.4	8.47	7.92	211.3	187.8	4.2	19.5	33.2	48.7
3	8.0	8.59	8.06	215.0	190.1	4.0	21.2	33.1	42.4
4	9.6	8.73	8.16	206.4	213.0	1.2	15.2	31.6	34.4
5	11.2	8.92	8.26	195.0	222.2	0.9	3.2	31.6	33.9
6	12.8	9.11	8.31	187.2	214.8	2.5	3.1	30.7	29.4
Σ		0.03	0.04	7.69	7.88	2.32	3.99	1.52	2.34

Trt	Δ pH	Δ NH ₄ ⁺	Δ NO ₂ ⁻	Δ NO ₃ ⁻	Δ (NO ₂ ⁻ + NO ₃ ⁻)
1	-0.63	-28.2	2.0	22.9	24.9
2	-0.55	-23.5	15.3	15.5	30.8
3	-0.53	-24.9	17.0	9.3	26.3
4	-0.57	6.6	14.0	2.8	16.8
5	-0.66	27.2	2.3	2.3	4.6
6	-0.80	27.6	0.6	1.3	1.9

* ppm nitrogen

Unionized Ammonia Levels

From the data in Table (13) it can be seen that as pH increased with the addition of Ca^{+2} the total amount of ammonium retained by the soil decreased and the amount of ammoniacal nitrogen in soil solution increased. An increase in solution ammoniacal nitrogen and an increase in pH caused a sharp increase in solution free ammonia as shown in Figure (29).

If the level of 12.8 ppm free ammonia-nitrogen is taken as the minimum level of toxicity (Smith, 1964) then Figure (29) indicates that the rate of 100 ppm added ammonia nitrogen did not reach toxic conditions of free ammonia until a pH above 9.0 was reached, but the 200 ppm rate reached toxic levels at around pH 8.8. This would indicate that the higher nitrogen rate would reach toxicity due to free ammonia before it would reach complete nitrification inhibition by high pH (pH 9.0) as was shown in the maximum pH nitrification study.

The other soils did not have the same ammonium adsorbing capacities on the cation exchange sites as the Vanoss silt loam (Table 14). The Blanket silt loam had less adsorbing capacity and the Hastings silt loam had more adsorbing capacity for ammonium as can be seen by their ammoniacal nitrogen concentrations in the soil solution.

The levels of ammoniacal nitrogen in the Hastings' soil solution did not appear to be low enough to suggest reduced availability to nitrifiers. The cause of the reduced nitrification in this soil is not understood.

Amending the soil with $\text{Ca}(\text{OH})_2$ and with aluminum hydroxide polymers both reduced the amount of ammonium adsorbed onto the exchange sites.

Table 13 Unionized ammonia levels for two added ammonia concentrations at different initial soil pH's.

Added Ammonia N	pH	NH ₄ (soil)	----- ppm N -----		NH ₃
			reduced N	reduced N	
			- soil weight basis-		
			- solution weight basis-		
100 ppm	7.61	108.9	2.7	18.0	0.41
	8.34	111.0	2.9	19.4	2.61
	8.81	91.2	3.8	25.6	6.90
	9.34	65.8	6.8	45.4	25.2
	10.23	54.8	9.7	65.0	58.9
200 ppm	7.57	160.8	4.3	28.9	0.60
	8.39	169.2	4.4	29.3	3.60
	8.98	158.5	5.7	37.7	13.3
	9.60	121.8	11.7	78.0	54.2
	10.13	76.0	16.2	108.2	95.8
0	0.04	11.1	0.99	6.59	

Figure 29 Unionized NH_3 levels for two added ammonia concentrations

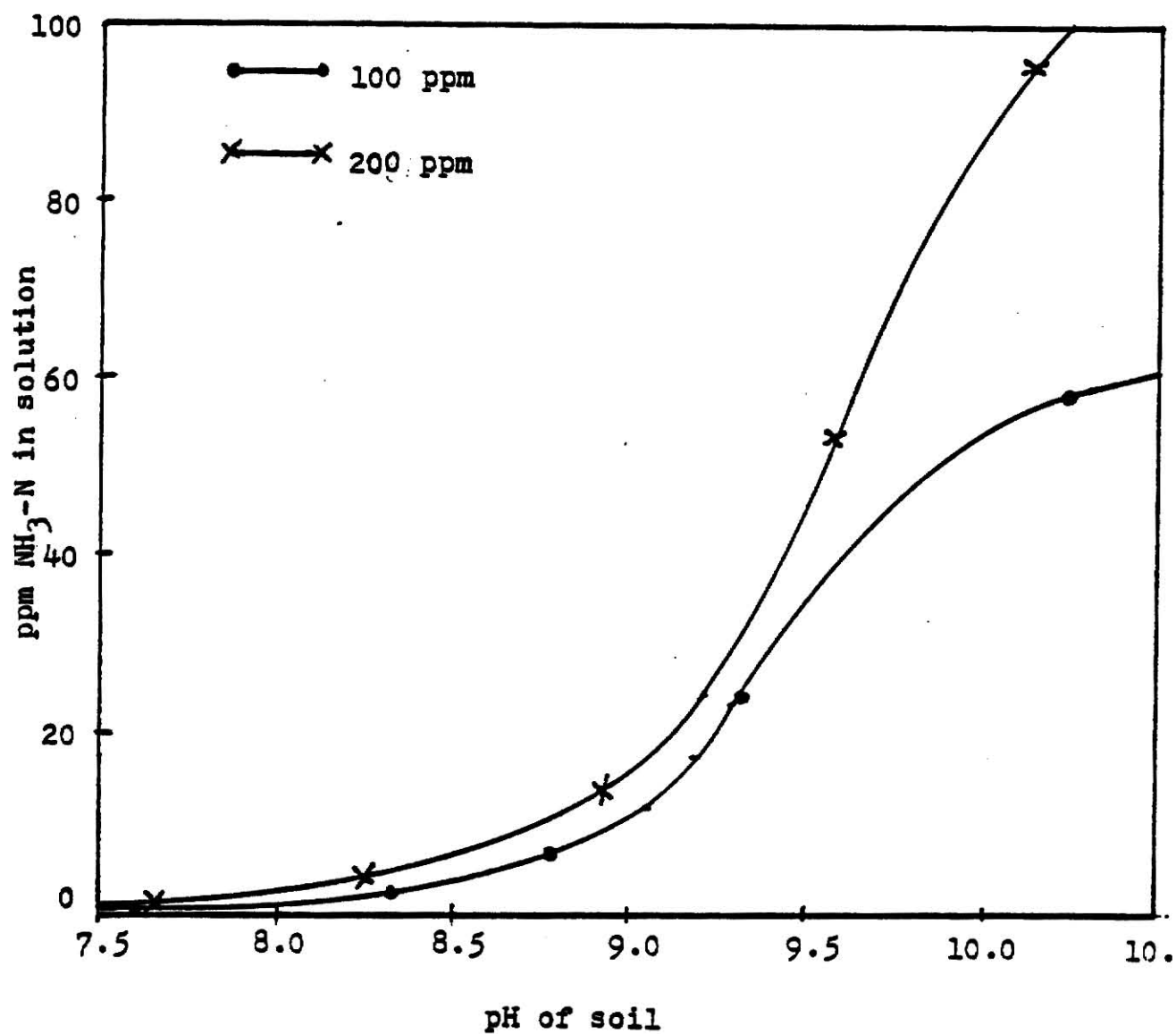


Table 14 Unionized ammonia levels for several soils at three high rates of added ammonia.

soil type	ppm added ammonia *	pH initial	ppm reduced nitrogen **	ppm ammonia nitrogen * *
Blanket silt loam	400	6.67	57	0.15
	600	7.59	115	2.52
	1200	8.50	228	35.0
Vanoss silt loam	400	6.69	46	0.13
	600	7.16	61	0.50
	1200	8.23	112	9.99
Hastings silt loam	400	6.93	38	0.18
	600	7.33	57	0.69
	1200	8.08	89	5.74
Vanoss moderate liming	400	7.77	49	1.60
	600	8.06	57	3.54
	1200	8.24	195	17.6
Vanoss heavy liming	400	8.56	75	13.0
	600	8.76	101	25.0
	1200	9.23	417	205
Blanket ₂ Al(OH) ⁺²	400	6.10	241	0.17
	600	6.65	274	0.70
	1200	7.39	559	7.74
Vanoss ₂ Al(OH) ⁺²	400	7.72	116	3.40
	600	7.78	183	6.09
	1200	7.95	372	18.1

* ppm nitrogen on a soil weight basis (rates on a soil solution weight basis would be 2664, 3996, and 7992 ppm)

** ppm nitrogen on a solution weight basis in soil solution at 15% moisture by weight.

This was probably due to competition of cation exchange sites with the calcium ions which were added in both treatments. The soils amended with aluminum hydroxide had their pH reduced to 4.0 and required large amounts of $\text{Ca}(\text{OH})_2$ to raise their pH back to higher levels. From the liming treatments it was observed that increasing the added calcium increased the amounts of ammoniacal nitrogen in solution. Increasing this ammoniacal nitrogen concentration would increase the chances of reaching toxic levels of free ammonia. This relationship would help explain the cause of increased inhibition at lower nitrogen rates and pH levels for several of the soils in the buffering capacity study.

In the first nitrification study the levels of added ammonia that gave nitrification inhibition had free ammonia nitrogen levels of 10 ppm or greater. This value corresponds well with the value given by Smith in his research (1964). The exceptions to this were the aluminum hydroxide amended soils which had lower toxic levels of free ammonia. Since these soils remained at a high pH longer it would appear that increasing the time of exposure to high concentrations of free ammonia must increase the toxicity effects. Here buffering capacity of the soil has one of its strongest effects.

Free ammonia toxicity like high pH toxicity would not have a sharp boundary between no toxicity and maximum toxicity. It appears the toxic boundary depends both on level of free ammonia and the time of exposure to a specific ammonia level. For the natural Kansas soils studied in these experiments the minimum toxic level of free ammonia to give almost complete inhibition was found to be approximately 10 ppm ammonia nitrogen in soil solution.

SUMMARY

Field Studies

It was observed in the time of application study that preplant dual knifed N-P fertilizer application gave a response of increased growth in the spring and better yields than all other methods of fertilizer applications studied. This improved crop response was present although nitrification in the N-P fertilizer brands was almost completed in the fall. Also, reduction of pH in these bands did not appear to be great enough to affect phosphorus availability.

Since most of the nitrogen and phosphorus was not taken up until spring differences due to nitrogen form applied would be due to differences that occur in the soil before nitrification and uptake. One soil factor strongly suggested in this and past studies would be movement of the nitrate nitrogen out of the fertilizer band.

The N-rate study showed the importance of nitrogen concentration in the band. This study showed that nitrogen concentrations can be important to phosphorus uptake even up to the highest N rate used in this study (180 kg N/ha). Also, increasing the nitrogen rate increased the yield in the dual knifed N-P applications even to the highest rates even if it did not greatly increase phosphorus uptake in the grain. In future studies care should be taken to separate any dual knifed response to phosphorus fertilizer efficiency increase from a direct N rate response when using different forms of fertilizer nitrogen which have different nitrogen fertilizer efficiencies.

Laboratory Studies

The first nitrification study suggested that buffering capacity is not important as long as the pH level is in a non-inhibitory range. This study also suggested that soils differ in their nitrification ability at high ammonium rates due to their control over soil solution concentrations of ammoniacal nitrogen and soil solution pH.

Buffering capacity was important initially in keeping the pH from increasing to high toxic levels with the addition of ammonia and later in keeping the soil at these high pH levels. When toxic pH levels were not reached, nitrification rates usually increased with pH even to levels above neutrality.

The acidity production study showed that nitrification appeared to follow theoretical reactions with aqua ammonia and urea nitrification producing around one meq. of H^+ per meq. of ammonia nitrified. And the ammonium sulfate produced about twice as much acidity per unit nitrogen nitrified as the theoretical reactions would indicate.

The maximum pH study gave a pH of 8.5 as the initial high pH level for showing inhibition of nitrification in the Vanoss soil. This study also showed that inhibition by high pH was not complete until pH 9.0 was reached. Also, free ammonia toxicity lowered the level of maximum pH for nitrification to occur by affecting the second step of nitrification. It appears that toxic levels of free ammonia are reached before pH 9.0 for all added ammonia rates of 200 ppm nitrogen and above for Kansas silt loams.

Looking at free ammonia levels explains some differences in the soil's nitrification responses at high pH. The free ammonia level

reached by a soil depends not only on pH and added ammonia rate but also on the amount of added ammonia which remains in solution. This solution concentration is dependent on both the soil's cation exchange capacity and the presence of cations competing for the exchange sites.

The toxic level of free ammonia was found to be approximately 10 ppm nitrogen in solution for the soils studied but this level could be reduced by increasing the time of exposure to a lower free ammonia level by increasing the soil's buffering capacity to slow any pH reduction.

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Appendix I Change in ammonium concentration and nitrate plus
nitrite concentration in fertilizer bands sampled.

		Depth (cm)	Sampling Date				
			Sept 18	Oct 11	Jan 3	April 24	
19 kg/ha N 19 kg/ha P Sept. application	ppm NH_4^+-N	0-10	9.3	13.6	7.7	6.9	
		10-20	7.5	3.2	9.1	6.8	
		20-30	6.8	5.6	7.0	8.1	
	ppm NO_2^--N and ppm NO_3^--N	0-10	11.3	11.7	11.8	3.9	
		10-20	5.0	3.6	14.2	3.7	
		20-30	4.6	1.1	9.9	3.8	
	pH	0-10				5.28	
		10-20				5.34	
		20-30				5.43	
	100 kg/ha N 19 kg/ha P Sept. application	ppm NH_4^+-N	0-10	75.5	50.8	13.2	6.9
			10-20	3.8	11.1	20.2	7.8
			20-30	5.9	3.4	9.2	7.2
ppm NO_2^--N and ppm NO_3^--N		0-10	26.1	28.5	40.3	5.7	
		10-20	4.1	4.7	43.4	7.2	
		20-30	1.8	2.6	27.2	13.5	
pH		0-10				5.12	
		10-20				5.15	
		20-30				5.55	
kg/ha N 19 kg/ha P Dec. application		ppm NH_4^+-N	0-10			55.9	9.7
			10-20			9.0	6.8
			20-30			13.7	7.8
	ppm NO_2^--N and ppm NO_3^--N	0-10			12.2	6.5	
		10-20			13.5	4.7	
		20-30			14.4	5.2	
	pH	0-10				5.24	
		10-20				5.35	
		20-30				5.49	
	100 kg/ha N 19 kg/ha P Dec. application	ppm NH_4^+-N	0-10			151.7	50.7
			10-20			8.9	9.6
			20-30			8.2	7.0
ppm NO_2^--N and ppm NO_3^--N		0-10			11.7	23.1	
		10-20			11.0	9.3	
		20-30			7.4	7.5	
pH		0-10				5.10	
		10-20				5.26	
		20-30				5.47	

	ppmN	Depth (cm)	Sampling Dates				
			8/28	9/27	10/26	1/4	5/23
kg/ha N 19 kg/ha P August application	NH ₄ ⁺	0-10	16.2	2.9	9.6	9.1	16.5
		10-20	11.6	2.8	9.1	7.2	13.4
		20-30	8.9	2.5	5.0	5.9	15.5
	NO ₂ ⁻ and NO ₃ ⁻	0-10	14.3	4.2	12.6	9.4	11.4
		10-20	10.6	2.7	7.0	9.4	10.1
		20-30	8.0	1.2	4.6	6.7	11.5
	pH	0-10					5.74
		10-20					5.68
		20-30					6.00
	NH ₄ ⁺	0-10	101.0	122.3	177.6	35.3	11.1
		10-20	18.5	6.4	102.2	34.1	14.1
		20-30	16.7	6.3	29.6	5.8	14.0
100 kg/ha N 19 kg/ha P August application	NO ₂ ⁻ and NO ₃ ⁻	0-10	13.9	15.1	17.2	20.8	15.9
		10-20	14.6	4.4	28.4	28.4	13.3
		20-30	10.7	2.4	8.7	14.8	16.1
	pH	0-10					5.54
		10-20					5.65
		20-30					6.18
kg/ha N 19 kg/ha P September application	NH ₄ ⁺	0-10		6.0	14.4	8.8	13.7
		10-20		4.8	5.1	5.5	12.6
		20-30		3.3	4.1	6.4	14.5
	NO ₂ ⁻ and NO ₃ ⁻	0-10		4.3	16.4	12.3	10.6
		10-20		2.5	7.6	7.9	9.4
		20-30		1.2	4.4	6.8	10.5
	pH	0-10					5.60
		10-20					5.58
		20-30					5.97
100 kg/ha N 19 kg/ha P September application	NH ₄ ⁺	0-10		137.8	116.6	36.1	15.8
		10-20		6.9	65.0	58.4	17.7
		20-30		3.9	17.2	48.9	15.7
	NO ₂ ⁻ and NO ₃ ⁻	0-10		7.4	18.3	40.6	25.3
		10-20		2.6	17.1	22.8	19.0
		20-30		2.0	10.9	30.0	19.0
	pH	0-10					5.45
		10-20					5.42
		20-30					5.90

Appendix I b) Dickinson County
continued

	ppm N	Depth	Sampling Dates	
			1/4	5/23
kg/ha N 19 kg/ha P December application	NH ₄ ⁺	0-10	86.5	13.9
		10-20	15.2	13.2
		20-30	5.7	12.7
	NO ₂ ⁻ and NO ₃ ⁻	0-10	9.6	12.2
		10-20	7.3	9.9
		20-30	10.0	10.4
	pH	0-10		5.63
		10-20		5.77
		20-30		6.16
	NH ₄ ⁺	0-10	124.4	36.5
		10-20	24.9	14.9
		20-30	6.2	15.0
100 kg/ha N 19 kg/ha P December application	NO ₂ ⁻ and NO ₃ ⁻	0-10	10.0	48.3
		10-20	9.4	13.6
		20-30	6.0	11.6
	pH	0-10		5.23
		10-20		5.56
		20-30		5.95

Appendix II Change in ammonium concentration, nitrate plus nitrite concentration, and pH over time during nitrification of several soils.

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+	41.0	31.7	25.7	19.9	18.9
	$\text{NO}_2^- + \text{NO}_3^-$	36.1	48.6	58.3	68.6	69.7
	pH	5.38	5.35	5.32	5.30	5.15
100	NH_4^+	132.5	88.4	75.7	49.6	48.4
	$\text{NO}_2^- + \text{NO}_3^-$	33.5	75.7	100.2	118.4	142.0
	pH	5.76	5.26	5.10	4.97	4.86
200	NH_4^+	207.9	202.7	166.6	109.0	94.5
	$\text{NO}_2^- + \text{NO}_3^-$	33.9	69.7	102.1	168.8	178.0
	pH	5.96	5.61	5.37	4.96	4.90
400	NH_4^+	430.0	392.8	269.1	263.5	196.0
	$\text{NO}_2^- + \text{NO}_3^-$	36.2	76.8	156.2	196.5	194.5
	pH	6.67	6.05	5.32	5.22	4.86
600	NH_4^+	561.4	471.0	328.8	241.3	178.5
	$\text{NO}_2^- + \text{NO}_3^-$	47.6	144.9	249.4	332.9	393.8
	pH	7.59	7.32	6.68	6.30	5.63
1200	NH_4^+	1118.1	1067.2	830.1	687.7	583.5
	$\text{NO}_2^- + \text{NO}_3^-$	40.6	106.4	329.8	430.3	516.0
	pH	8.50	7.74	6.42	5.94	5.79
$\hat{\sigma}$	NH_4^+	62.3	73.2	121.1	95.6	104.3
	$\text{NO}_2^- + \text{NO}_3^-$	8.1	53.3	114.1	110.7	113.7
	pH	0.64	0.62	0.96	1.13	1.18

* ppm Nitrogen

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+	8.4	2.4	3.6	3.3	3.7
	$\text{NO}_2^- + \text{NO}_3^-$	35.5	37.9	40.9	42.3	48.3
	pH	5.62	5.55	5.57	5.51	5.49
100	NH_4^+	96.6	68.1	45.8	38.2	27.7
	$\text{NO}_2^- + \text{NO}_3^-$	31.8	73.2	91.5	104.8	121.1
	pH	5.65	5.30	5.12	4.99	4.92
200	NH_4^+	206.6	162.0	118.7	113.4	99.0
	$\text{NO}_2^- + \text{NO}_3^-$	32.0	85.3	120.0	139.9	149.5
	pH	6.16	5.58	5.24	5.14	5.05
400	NH_4^+	386.0	333.4	261.3	223.1	134.6
	$\text{NO}_2^- + \text{NO}_3^-$	34.4	90.1	167.4	212.6	257.2
	pH	6.69	5.97	5.35	5.09	4.85
600	NH_4^+	548.9	509.0	426.1	374.3	339.6
	$\text{NO}_2^- + \text{NO}_3^-$	42.8	86.2	170.3	177.9	236.2
	pH	7.16	6.61	5.81	5.74	5.00
1200	NH_4^+	1107.2	1078.6	829.7	760.2	655.6
	$\text{NO}_2^- + \text{NO}_3^-$	52.5	100.6	298.6	331.2	421.0
	pH	8.23	7.73	6.20	5.44	4.71
$\hat{\sigma}$	NH_4^+	37.9	41.8	65.5	90.1	61.4
	$\text{NO}_2^- + \text{NO}_3^-$	4.4	20.8	94.9	93.7	57.1
	pH	0.21	0.34	0.84	0.80	0.55

* ppm Nitrogen

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+	15.8	24.6	8.2	10.2	9.8
	$\text{NO}_2^- + \text{NO}_3^-$	36.7	39.8	42.2	47.4	51.5
	pH	5.81	5.83	5.75	5.66	5.62
100	NH_4^+	92.0	77.0	50.4	54.7	57.5
	$\text{NO}_2^- + \text{NO}_3^-$	33.8	47.4	67.8	70.2	87.9
	pH	5.93	5.78	5.58	5.60	5.39
200	NH_4^+	196.2	196.0	177.5	161.8	134.6
	$\text{NO}_2^- + \text{NO}_3^-$	35.8	43.4	54.5	61.1	96.3
	pH	6.38	6.34	6.16	6.03	5.70
400	NH_4^+	347.4	361.6	342.1	324.4	306.3
	$\text{NO}_2^- + \text{NO}_3^-$	38.1	49.9	59.7	77.0	107.7
	pH	6.93	6.74	6.56	6.44	6.10
600	NH_4^+	561.9	552.5	534.9	507.0	466.7
	$\text{NO}_2^- + \text{NO}_3^-$	28.8	53.4	54.8	83.1	113.8
	pH	7.33	7.10	7.09	6.80	6.58
1200	NH_4^+	1044.6	1094.8	963.6	864.3	767.4
	$\text{NO}_2^- + \text{NO}_3^-$	40.8	67.5	183.3	198.4	173.3
	pH	8.08	7.74	7.12	6.71	6.49
∞	NH_4^+	20.8	15.5	55.1	86.3	52.3
	$\text{NO}_2^- + \text{NO}_3^-$	5.5	16.5	52.7	84.1	52.8
	pH	0.13	0.20	0.53	0.70	0.81

* ppm Nitrogen

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	38.6	38.1	32.8	34.0	33.2
		29.0	38.0	45.2	48.6	55.3
		5.92	5.65	5.47	5.32	4.95
100	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	135.3	104.6	83.4	61.1	76.4
		34.9	70.8	92.3	91.5	101.2
		6.82	6.06	5.72	5.47	5.52
200	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	210.3	152.2	121.8	120.8	86.8
		32.6	91.8	84.1	94.3	95.3
		7.81	6.31	5.95	5.84	5.39
400	NH_4^+ $\text{NO}_3^- + \text{NO}_2^-$ pH	292.0	220.5	214.1	202.7	190.9
		31.4	30.0	43.5	42.3	58.4
		7.97	7.52	7.31	7.18	6.75
600	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	270.6	261.2	246.8	243.5	226.0
		32.8	29.1	39.0	32.1	87.3
		8.00	7.68	7.51	7.52	6.86
σ	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	22.0	39.9	36.5	39.7	29.3
		3.5	18.5	11.6	13.8	32.7
		0.45	0.31	0.35	0.47	0.64

* ppm nitrogen

Rate ppm N		Days				
		0	10	20	30	40
0	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	27.2	7.7	7.6	9.8	13.7
		26.8	50.3	54.5	58.0	68.3
		6.76	6.48	6.40	6.37	6.30
100	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	102.3	50.9	9.8	8.1	12.6
		28.9	91.7	128.0	143.2	154.6
		7.02	6.41	6.04	5.99	5.97
200	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	197.4	135.9	50.3	11.7	16.4
		29.5	110.2	186.4	241.9	250.8
		7.29	6.48	5.85	5.55	5.50
400	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	369.7	313.1	196.0	65.0	38.7
		29.9	131.7	206.0	295.5	415.0
		7.77	6.81	5.62	5.07	4.89
600	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	553.7	436.6	258.6	207.3	130.2
		30.5	142.6	335.8	380.7	414.8
		8.06	7.08	5.52	5.45	4.86
1200	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	1063.9	1055.3	1014.2	844.0	798.0
		50.0	61.6	151.2	291.5	345.8
		8.24	8.02	7.76	7.13	6.80
$\hat{\sigma}$	$\frac{\text{NH}_4^+}{\text{NO}_2^- + \text{NO}_3^-}$	27.2	44.7	79.4	55.9	25.4
		29.8	27.1	71.4	39.0	32.9
		0.04	0.20	0.10	0.20	0.09

* ppm Nitrogen

Appendix II f)

Vanoss Heavy Liming

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+	32.4	12.6	12.3	12.3	10.4
	$\text{NO}_2^- + \text{NO}_3^-$	42.3	85.3	87.7	100.4	109.5
	pH	8.12	7.94	7.96	7.87	7.89
100	NH_4^+	123.3	21.3	15.6	12.1	12.5
	$\text{NO}_2^- + \text{NO}_3^-$	62.9	155.4	171.0	180.7	188.7
	pH	8.32	7.80	7.80	7.75	7.77
200	NH_4^+	215.8	66.5	14.0	13.1	13.0
	$\text{NO}_2^- + \text{NO}_3^-$	44.6	195.7	267.2	268.8	282.6
	pH	8.35	7.71	7.69	7.65	7.67
400	NH_4^+	384.4	299.1	31.3	15.0	14.2
	$\text{NO}_2^- + \text{NO}_3^-$	46.1	165.1	469.5	426.9	463.6
	pH	8.56	7.98	7.29	7.17	7.30
600	NH_4^+	562.1	547.7	283.3	102.3	21.5
	$\text{NO}_2^- + \text{NO}_3^-$	42.6	93.6	307.8	501.0	584.9
	pH	8.76	8.26	7.62	7.06	6.79
1200	NH_4^+	973.5	970.9	951.5	864.9	828.9
	$\text{NO}_2^- + \text{NO}_3^-$	43.3	42.0	53.0	80.0	187.6
	pH	9.23	8.59	8.63	8.42	8.07
$\hat{\sigma}$	NH_4^+	0.0	0.0	5.3	14.4	40.3
	$\text{NO}_2^- + \text{NO}_3^-$	11.2	26.6	42.3	16.0	49.6
	pH	0.03	0.05	0.06	0.07	0.10

* ppm Nitrogen

Appendix II g)

Blanket Aluminum Hydroxide

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+	37.7	37.3	44.4	37.3	42.5
	$\text{NO}_2^- + \text{NO}_3^-$	14.5	17.2	21.2	21.5	30.2
	pH	4.93	4.91	4.89	4.85	4.87
100	NH_4^+	135.2	131.8	119.2	87.4	112.7
	$\text{NO}_2^- + \text{NO}_3^-$	15.6	21.0	49.9	78.6	66.4
	pH	5.31	5.11	5.07	4.79	4.88
200	NH_4^+	244.0	225.0	244.0	210.1	209.1
	$\text{NO}_2^- + \text{NO}_3^-$	16.8	19.7	26.9	47.1	60.7
	pH	5.53	5.45	5.29	5.29	5.21
400	NH_4^+	461.0	404.4	411.2	398.1	390.2
	$\text{NO}_2^- + \text{NO}_3^-$	15.6	21.0	33.9	66.3	67.0
	pH	6.10	5.84	5.77	5.68	5.54
600	NH_4^+	663.7	668.3	676.2	665.0	634.1
	$\text{NO}_2^- + \text{NO}_3^-$	15.6	19.3	27.5	38.2	58.2
	pH	6.65	6.39	6.26	6.16	6.10
1200	NH_4^+	1262.5	1218.5	1164.8	1065.8	1053.2
	$\text{NO}_2^- + \text{NO}_3^-$	15.1	19.1	26.9	43.6	168.5
	pH	7.39	7.27	7.05	6.83	6.22
$\hat{\sigma}$	NH_4^+	11.7	48.8	24.9	29.1	29.1
	$\text{NO}_2^- + \text{NO}_3^-$	1.7	2.4	12.0	22.5	31.1
	pH	0.08	0.09	0.15	0.12	0.19

* ppm Nitrogen

Rate ppm N		Days				
		0	10	20	30	40
0	NH_4^+	41.7	51.7	56.9	57.5	48.1
	$\text{NO}_2^- + \text{NO}_3^-$	14.3	16.9	21.5	22.3	25.4
	pH	7.09	7.13	7.17	7.17	7.22
100	NH_4^+	145.6	147.2	137.2	135.2	102.6
	$\text{NO}_2^- + \text{NO}_3^-$	14.1	19.1	34.0	42.2	85.5
	pH	7.16	7.15	7.19	7.14	7.08
200	NH_4^+	212.9	211.2	134.7	84.1	20.5
	$\text{NO}_2^- + \text{NO}_3^-$	16.8	28.1	106.4	153.6	249.4
	pH	7.52	7.50	7.33	7.16	6.99
400	NH_4^+	398.8	374.5	243.9	224.9	98.6
	$\text{NO}_2^- + \text{NO}_3^-$	17.8	23.2	168.8	221.6	331.1
	pH	7.72	7.57	7.43	7.22	6.89
600	NH_4^+	578.4	562.0	547.6	392.2	445.3
	$\text{NO}_2^- + \text{NO}_3^-$	16.3	17.1	57.5	102.8	157.9
	pH	7.78	7.63	7.49	7.45	7.42
1200	NH_4^+	947.7	953.6	999.2	1014.6	919.1
	$\text{NO}_2^- + \text{NO}_3^-$	18.0	21.2	20.1	26.8	58.6
	pH	7.95	7.57	7.57	7.55	7.64
$\hat{\sigma}$	NH_4^+	62.7	88.3	115.8	126.5	127.4
	$\text{NO}_2^- + \text{NO}_3^-$	1.7	6.2	45.0	65.0	50.3
	pH	0.20	0.23	0.23	0.23	0.20

* ppm Nitrogen

Rate ppm N		Days				
		00	10	20	30	40
0	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	8.4	2.4	3.6	3.3	3.7
		35.5	37.9	40.9	42.3	48.3
		5.62	5.55	5.57	5.51	5.49
100	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	124.9	103.7	103.8	86.8	65.6
		41.9	61.5	76.2	75.9	87.4
		5.44	5.14	5.04	5.07	4.89
200	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	192.2	188.6	161.1	168.0	152.1
		41.3	57.9	68.5	78.1	83.8
		5.23	5.14	5.06	5.00	4.92
400	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	376.7	389.8	378.4	333.2	348.5
		41.3	50.4	65.3	75.4	85.8
		5.14	5.05	4.98	4.93	4.85
600	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	567.3	574.5	559.6	538.4	538.3
		43.5	54.7	59.1	76.2	80.6
		5.06	5.04	4.95	4.88	4.85
1200	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	1134.7	1223.6	1176.9	1065.1	1104.4
		49.5	65.8	71.8	77.3	95.4
		4.85	4.73	4.65	4.59	4.85
$\hat{\sigma}$	NH_4^+ $\text{NO}_2^- + \text{NO}_3^-$ pH	23.1	36.6	7.6	48.7	23.8
		6.7	4.7	10.4	15.2	17.6
		0.10	0.16	0.18	0.25	0.23

* ppm Nitrogen

Vita

The author was born on December 19, 1956 in Wichita, Kansas. He lived with his parents at St. Mark, Kansas until 1975 at which time he entered Benedictine College. In the fall of 1977 he transferred to Kansas State University. He completed a Bachelor of Science Degree in agronomy in May of 1979. He then entered graduate school at Kansas State University to work on a Master of Science Degree in agronomy under Dr. D. E. Kissel who employed him as a graduate research assistant.

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NITRIFICATION IN PREPLANT N-P FERTILIZER
BANDS AND PH EFFECTS ON NITRIFICATION

by

NICHOLAS MARK BETZEN

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ABSTRACT

Two studies were conducted on 1980 winter wheat crops to determine the effect of nitrification on response of applying nitrogen fertilizer with phosphorus fertilizer in preplant bands. Further, the studies were designed to see if the nitrification observations could explain past studies' variable response to nitrogen form in the dual knifed N-P applications. Nitrification rates were varied by changing the time of fertilizer application in the fall and by increasing the N rate.

It was found that adding nitrogen to the bands increased phosphorus uptake even though nitrification was almost complete by the end of fall. Since this occurred before the nutrients were taken up in large amounts, any initial difference in nitrogen form would be due to soil factors. It was found that pH changes in the bands were not great enough to affect phosphorus availability. It was concluded that nitrogen movement out of the bands was probably a major reason for differences in N-form responses in earlier dual knifed N-P studies.

Increasing the N-rate showed that phosphorus uptake from dual knifed N-P bands could be increased by increasing the band nitrogen concentration even to the highest rate of added fertilizer nitrogen in this study (180 kg N/ha). Also it was found that high N-rates could increase yield without greatly increasing total phosphorus uptake by maturity.

Laboratory studies simulating ammonia band conditions showed that buffering capacity of a soil is important in regulating pH immediately after ammonia application and during the following nitrification process.

At high pH levels it was found that there is a maximum pH value of about 9.0 for nitrification and that this value can be reduced by the presence of free ammonia toxicity conditions. Free ammonia levels were found to be determined by pH and concentrations of ammoniacal nitrogen in the soil solution.

The concentration of ammoniacal nitrogen in solution is dependent on amount of added ammonia, the soil's cation exchange capacity and the activity of cations competing for exchange sites.

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