I. EFFECT OF TIME AND RATE OF APPLICATION OF ANHYDROUS AMMONIA ON YIELD AND PROTEIN CONTENT OF WINTER WHEAT

II. EFFECT OF NITROGEN FERTILIZATION, PLACEMENT OF NITROGEN, AND PHOSPHORUS SOURCE ON THE AVAILABILITY OF PHOSPHORUS TO WINTER WHEAT

By

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INTRODUCTION

PART I

Anhydrous ammonia is a nitrogenous compound manufactured from purified hydrogen and nitrogen. Under specified conditions of pressure and temperature and in the presence of an iron catalyst, hydrogen and nitrogen are combined to form anhydrous ammonia. It contains 82 percent nitrogen and weighs 5 pounds per gallon at 80 degrees F. At lower temperatures it weighs slightly more and at higher temperatures, slightly less. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. At -28 degrees F. and lower and at atmospheric pressure it is a liquid. Anhydrous ammonia has a gauge pressure of 75 pounds per square inch at 50°F., and 197 pounds per square inch at 100°F.

The direct application of anhydrous ammonia to the soil as a nitrogen fertilizer for agricultural crops is a relatively new practice. In 1947, W. B. Andrews and F. E. Edwards of Mississippi State College developed equipment suitable for applying anhydrous ammonia directly into the soil.

Anhydrous ammonia, when injected into a soil, immediately reacts with the soil water and forms ammonium hydroxide. Ammonoum hydroxide dissociates into ammonium (NH_4^+) ions and hydroxyl ions (OH^-). The ammonium (NH_4^+) ion will replace some positively charged ion, such as H^+ or Ca^{++}, on the clay. If hydrogen is replaced, it may react with the free hydroxyl and again form water.

Young cotton and corn plants respond to nitrogen treatment better when their source of nitrogen is ammonia than when it is nitrate, but as the plants grow older, they respond better to nitrate nitrogen.

In general, field tests have shown anhydrous ammonia to be fully as good as other commonly used materials, such as sodium nitrate, ammonium nitrate, and ammonium sulfate. Studies have indicated that its rate of nitrification in most agricultural soils is sufficiently rapid to provide adequate nitrate for plant development.

Ammonia exists as a positively charged ion. As such, it has a retention advantage in soil over the negatively charged nitrate ion. This is due to the negatively charged characteristic of the clay colloid. Its greater resistance to leaching should make possible larger and less frequent applications as compared to materials in which nitrogen is in nitrate form. Due to its physical state, it is better adapted to deep placement than the solid forms of nitrogen.

It is one of the cheapest nitrogen fertilizers. It is the first product of nitrogen fixation by the Haber-Bosch process, thus manufacturing costs are relatively low per unit of nitrogen. Anhydrous ammonia has two outstanding disadvantages: (1) expensive pressure equipment is needed to handle it and (2) present equipment for distribution is not well suited for use on fields containing roots or other obstructions.

The objectives of this experiment were: (1) to determine the most efficient time for applying anhydrous ammonia as a source of nitrogen for winter wheat and (2) to determine the nitrogen needs for maximum wheat production on a Dennis Silt loam soil in Rogers County, Oklahoma.

REVIEW OF LITERATURE

Previous studies have been centered primarily around the use of anhydrous ammonia as a source of nitrogen, the comparison of anhydrous ammonia with other nitrogen carriers, its effect upon microorganism activity, and its distribution and retention in the soil.

In 1951, Andrews and co-workers (7)[1] reported data obtained from experiments comparing anhydrous ammonia and ammonium nitrate as side-dressings for cotton. This work was conducted in 1944. The anhydrous ammonia, applied 5 inches deep, was much superior to surface applied ammonium nitrate in most of the tests. This was attributed to the anhydrous ammonia being placed in a more advantageous place. They concluded that these data emphasize, primarily, the desirability of applying solid sources of nitrogen in the root zone during dry seasons, rather than a difference in the potential efficiency of these sources of nitrogen. In later experiments, conducted in 1945 through 1951, they showed that when anhydrous ammonia and ammonium nitrate were used as side-dressings for cotton, the anhydrous ammonia was slightly superior to ammonium nitrate. Each source of nitrogen was placed 4 inches deep. They also found the 6 inch depth superior to the 4 inch depth for applying nitrogen-containing fertilizers.

In twelve tests with cotton in wet years, Andrews (3) showed that anhydrous ammonia was slightly superior to ammonium nitrate applied at

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[1]Figure in parenthesis refers to Literature Cited.

planting time. In the same test, yield increases from side-dressings of anhydrous ammonia were slightly greater than those from ammonium nitrate. Andrews showed that cotton, side-dressed during a dry year, yielded much better when anhydrous ammonia was used than when ammonium nitrate was the source of nitrogen.

In an experiment with nitrogen applied before planting, Andrews and co-workers (5) found the following: (a) Cotton and corn plants grew off more rapidly when anhydrous ammonia, rather than ammonium nitrate, was applied as the source of nitrogen. (b) Young cotton and corn plants prefer ammonia nitrogen to nitrate nitrogen. (c) Ammonia should be applied immediately before planting because if it is applied too soon, the ammonia may be changed to nitrate before the young plants can utilize any of the ammonia. (d) Ammonia fumes are toxic to cotton plants, and precautions should be taken when anhydrous ammonia is being used as a side-dressing. (e) Ammonia was toxic to germinating seed when applied in the seed zone; but, when the ammonia was applied 4 to 6 inches below the seed, no injury to germination was observed.

Weldon and Ringler (52) found that anhydrous ammonia applied to corn prior to planting increased yields as much as ammonium nitrate applied as a side-dressing, but that ammonium nitrate was slightly superior to anhydrous ammonia when the two sources of nitrogen were applied as side-dressings. They concluded that anhydrous ammonia was about as good as other nitrogen fertilizers for the production of corn, wheat, and bromegrass.

Tests conducted in 1945 through 1947 by Andrews and co-workers (6,7) showed that anhydrous ammonia, when applied as a side-dressing, increased corn yields 16.2 bushels per acre. Ammonium nitrate, applied 4 inches deep as a side-dressing, increased yields 14.3 bushels per acre. They concluded that, when anhydrous ammonia and ammonium nitrate were applied to corn, the ammonia was somewhat superior to the nitrate.

Andrews (3) found anhydrous ammonia superior to ammonium nitrate when applied to corn at planting time, regardless of wet or dry seasons. He explained the difference between nitrogen sources on the basis of preference of young plants for ammonia, and of loss of nitrate through leaching.

Tests conducted by Thornton (51) in 1950 showed that anhydrous ammonia gave excellent results when applied previous to planting or as a side-dressing to growing crops.

According to Karraker and Kelley (23), crops require more nitrogen than any other plant food taken from the soil. They reported the approximate nitrogen requirement for a 100 bushel per acre corn crop, grain and forage, to be 150 pounds of nitrogen per acre.

Hammons (20) found fall applied anhydrous ammonia and ammonium nitrate to be equally effective for the production of forage from fall planted oats. He also found that when high yields of forage were obtained, fall applied nitrogen, at the rate of 30 pounds per acre, did not influence grain yields, but when an additional application of 30 pounds of nitrogen was made in the spring, increased grain yields were obtained. He concluded that when oats are planted for grazing in the early fall, high rates of nitrogen may be used, and that the greater part of the reduction in the yield of grain usually attributed to grazing, may be due to the removal of nitrogen in the forage.

Andrews and others (7) reported that fall applied ammonium nitrate on oats was a poor source of nitrogen as compared to fall applied anhydrous ammonia or spring applied ammonium nitrate.

Andrews (3) found that soil acidity greatly influenced the effectiveness of anhydrous ammonia on oats. Results from 5 strongly acid soils (pH 5.1 or lower) showed that fall applied anhydrous ammonia was equal or superior to spring applied ammonium nitrate. In 5 less-acid soils (pH 5.5 or higher) oat yields were higher from spring applied ammonium nitrate than from fall applied anhydrous ammonia.

According to Andrews and co-workers (6), when anhydrous ammonia was applied on oats in the fall on soils of pH 5.5 or higher, the ammonia was changed to nitrate; and it was removed through leaching before spring. This resulted in decreased yields as compared to spring applied anhydrous ammonia. Other tests showed that when ammonia was applied in the spring on soil of pH 5.5 or above, the ammonia was nitrified sufficiently fast for favorable results, but when applied in the spring to soils of pH 5.1 or less, nitrification was too slow for favorable results. They concluded that for oats, ammonia should be applied in the fall on soils of pH 5.1 or less and in the early spring on those above pH 5.1.

Luebs and others (27) found, from experiments on nitrogen fertilization of winter wheat in Nebraska, that anhydrous ammonia, applied at planting time, increased yields more than the same amount of nitrogen as ammonium nitrate. However, spring applied ammonium nitrate was superior to the planting time application of ammonium nitrate.

According to Wyche and co-workers (54), anhydrous ammonia is as efficient a source of nitrogen as sulfate of ammonia for the production of rice, if it is applied just before planting time. It may also be applied in the irrigation water if precautions are taken to get an even distribution of ammonia. In another experiment conducted at Stuttgart, Arkansas by Beacher (8), anhydrous ammonia gave profitable yield increases on rice. These increases were equal to or better than those from ammonium nitrate. He found that anhydrous ammonia gave best yield increases when injected directly into the soil before or within two weeks after planting. He also found that ammonia may be applied in the winter months without loss of nitrogen by leaching, because of the impervious subsoil that is characteristic of rice soils.

Campbell (11) found anhydrous ammonia and ammonium nitrate equally effective for the production of cabbage, beans, and tomatoes. His data indicate that anhydrous ammonia applied six inches deep, was superior to that applied four inches deep. He also found that the development of concentric growth cracks on tomato fruits was associated with the time of application of anhydrous ammonia in the 1949 season.

Schell (39) of Oregon reported that a deep application of anhydrous ammonia brings about speedy rotting of raw straw to form humus. In a test where 1300 pounds of sulfate of ammonia was used in surface applications over a three year period, the previously plowed-in straw failed to rot, although rotting took place at once after plowing and applying anhydrous ammonia.

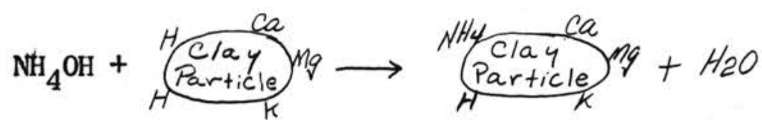
Smith (42) said that anhydrous ammonia dissolves organic matter and redistributes it sufficiently on the surface of the mineral soil particles to form water stable aggregates or granules, thereby improving the structure of the soil. He indicated that the plowing down of corn stalks or wheat stubble without added nitrogen results in all of the readily available nitrogen being used by soil bacteria and other organisms which serve to decompose the organic matter. He stated that additions of anhydrous ammonia in the autumn not only prevent this, but also help build up active organic matter.

According to Peech (35), the uptake of ammonia may be attributed primarily to two distinct mechanisms: (a) exchange adsorption of ammonium ions, and (b) solubility of ammonia in the soil water. The ammonium retention capacity due to exchange adsorption is determined primarily by the exchangeable hydrogen content, which in turn depends upon the pH and the amount of clay and organic matter present in the soil. He reported that for every m.e. of exchangeable hydrogen per 100 grams of soil, the soil will take up 280 pounds of anhydrous ammonia nitrogen per acre. He found that some soils would take up and retain ammonia in excess of the exchangeable hydrogen content. He concluded that this uptake of ammonia by soils in excess of the exchangeable hydrogen content was due to some reaction of anhydrous ammonia with the soil organic matter.

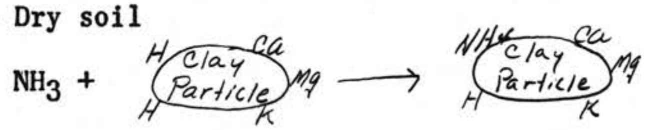
Stanley and Smith (47) reported that when anhydrous ammonia was applied to soil, it was assumed that one of the following reactions takes place.

(1) - Wet soil

$$NH_3 + H_2O \longrightarrow NH_4OH$$



(2) - Dry soil



In their studies of movement of ammonia from the point of release, they found lateral movement greater than movement toward the surface and movement toward the surface greater than downward movement.

According to studies by Blue and Eno (10), the ammonia was found to be concentrated in zones from 2 to 8 inches wide, depending on the soil moisture content. When rates as high as 258 pounds per acre of nitrogen were applied most of the ammonia was usually concentrated in a zone 3 inches wide.

Laboratory and field studies conducted by Anderson and Purvis (2) indicated that anhydrous ammonia may have certain advantages over other nitrogen carrying materials commonly used as fertilizers. When ammonia is injected into the soil, it increases the pH of the soil in the zone of injection to above 10.0 and holds it above 8.0 for about 14 days. This retards the action of the nitrifying bacteria which change ammonia to nitrate and allows the ammonia to remain in the soil for a longer period of time. Since plants can utilize ammonia as well as nitrate, and nitrogen in the ammonia form is not subject to loss through leaching, this property may be of considerable practical value under some conditions. They also found that when the soil temperature was below 40^{o}F., very little ammonia was nitrified thus fall application would result in the ammonia staying in this form during the winter, unless the soil temperature rose above 40^{o}F.

Allison (1) showed (a) that subsoils fix much more ammonia than surface soils, (b) that more fixation may occur in soil if the predominant clay mineral is illite or vermiculite rather than montmorillonite or koalonite, (c) that fixation is increased by drying and heating, and (d) that montmorillonitic clays fix little ammonia unless heated. He concluded that ammonia fixation is a factor of importance in agriculture, especially where ammonium fertilizers are added to the plow sole of non-kaolinitic soils.

According to Andrews (4), ammonia was converted into nitrate in about 6 weeks in fertile soil during warm weather. When the weather was cold or the soil wet or extremely acid, the rate of change was slower. Frederick (17) said that the pH range through which nitrification takes place is from 4.0 to about 8.5. Nitrification occurs at all temperatures from 32°F. to 105°F., but over this temperature range the amount of ammonia oxidized varies considerably, from 2 to 10 pounds per acre per week to 200- 400 pounds per acre per week. He also stated that if the soil is too dry, nitrification will not occur, and if it is too saturated, nitrification will be retarded because of lack of oxygen.

Eno and his co-workers (15) found, in their study of the effect of anhydrous ammonia on microorganisms, that the number of fungi and nematodes was reduced by all levels of ammonical nitrogen. Only 0.6 percent of the nematodes and 4.9 percent of the fungi survived when 608 parts per million of nitrogen was present in the soil. Field studies showed that re-establishment of the nematodes was greatest among the saprophytic species and was of the same character as that following fumigation with conventional nematocides. Their nitrification studies indicated that nitrification was slowed down in the area of the retention zone, but that the nitrifying bacteria gradually nitrified the ammonia until they utilized all of the ammonia. They found that applications of ammonia up to 320 parts per million were converted to nitrate efficiently, but at higher application rates, the rate of conversion of ammonia to nitrate was reduced significantly.

Eno and Blue (14) found that both bacteria and actinomycetes increased in number after anhydrous ammonia was applied until about 4 weeks after application when the soil became more acid and they were then decreased. Fungi decreased in number when the soil was treated with anhydrous ammonia for a period of about 5 weeks. They concluded that pH was the influencing factor upon the microorganisms. In their study on nitrification, they found that the nitrifiers change anhydrous ammonia to nitrate twice as fast as they nitrified ammonium sulfate.

Martin and Chapman (28) found that when the pH of a soil exceeded approximately 7.0 and ammonium was present in the soil, some of the ammonia was lost by volatilization. They showed that appreciable ammonia was lost from the soil only when there was a simultaneous loss of moisture; also the higher the temperature of the soil, the more rapid the loss. It was found that more ammonia was lost from surface applied ammonia hydroxide than from either ammonium sulfate or ammonium nitrate. This greater loss was attributed to the increase of pH brought about when ammonium hydroxide was applied to the soil. They also found that more ammonia volatilized from sodium and potassium soils than from calcium and magnesium soils, probably because of the higher pH of the soil containing the former.

Jackson and Chang (22) showed that if the soil was of intermediate texture, moisture content, and pH, an application of 60 pounds of nitrogen per acre in the form of anhydrous ammonia at a depth of 1 to 2 inches was practically all adsorbed instantly, and that there was little loss by gaseous diffusion. They found that coarse textured soil retained the gaseous ammonia with approximately as great efficiency as did heavier textured soil.

Blue and Eno (9) found that the distance of movement of ammonia was relatively small. Both soil moisture content and pH significantly affected the capacity for ammonia retention. The field retention of ammonia was found to be quite variable among soils, and loss of ammonia was as great as 75 percent. Low exchange capacity, high pH and low moisture content represented the poorest combination for retention. They concluded that with present methods of application, losses of nitrogen from applications of anhydrous ammonia on the lighter, sandy soils do occur, and in some cases prevent its economical use.

Tests by Schreven (40), in 1948, showed that an appreciable amount of ammonia applied on the surface of calcareous soil was lost by evaporation. He theorized that this loss might be reduced when the fertilizers are mixed with the soil immediately after application.

Newton, in his report of safe handling of anhydrous ammonia, (33) concluded that ammonia could be handled without danger if simple rules and regulations were followed. He stated that the best immediate treatment for a person who had been in contact with liquid ammonia was to deluge the affected part with water.

MATERIALS AND METHODS

This study was conducted on a Dennis silt loam soil located on the Paul Flemming farm approximately 2½ miles northeast of Inola, Oklahoma in the N.W. ¼, section 35, T. 20 N. R. 17 E. in Rogers county, Oklahoma.

The Dennis series[1] includes dark-colored soils of the transition between Prairie and Reddish Prairie soil zones developed principally from noncalcareous siltstones and silty shales with occasional layers of fine-grained sandstone. The series occupies areas of northeastern Oklahoma, southeastern Kansas, and adjoining areas in Missouri and Arkansas. Topography is undulating, with slope gradient ranging from about 1 to 3 percent in most places. External drainage is slow to moderately rapid. Internal drainage is moderately slow but adequate for all dry-farmed crops. The native vegetation is composed chiefly of tall grasses, principally big and little bluestem (*Andropagon furcatus* and *A. scoparius*). These soils are nearly all cultivated, the principal crops are corn and small grain.

History of Cropping System and Soil Analysis

The soil on which the study was conducted had been cropped to wheat and oats for the past 7 or 8 years without any fertilizer treatment. The soil was analyzed in the soil management laboratory at Oklahoma Agricultural and Mechanical College. All analyses, with the exception of nitrates

[1]Description of the Dennis series in the Appendix Table (I).

(45), nitrifiable nitrogen (45) and available phosphorus (50) were made according to the methods outlined by Harper (21).

The results of the soil analyses are presented in Table (1). These results indicate that the soil was relatively high in nitrogen, nitrates, and organic matter, however, there was no nitrifiable nitrogen. The soil was also relatively high in available phosphorus, but low in exchangeable potassium. The soil was acid in reaction.

Table 1. Soil Analyses of Dennis Silt Loam

Analysis	Results 0-6" Depth	6-12" Depth
Texture	18% Sand 66% Silt 16% Clay	16% Sand 50% Silt 34% Clay
Reaction (pH)	4.8	4.8
Nitrogen	.117%	.106%
Nitrates	54 lbs/A.	54 lbs/A.
Nitrifiable nitrogen	None	None
Organic Matter	2.0%	--
Available Phosphorus	25.2 lbs/A	9.16 lbs/A.
Exchangeable potassium	26 lbs/A.	26 lbs/A.

Treatments and Methods of Application

Anhydrous ammonia was the source of nitrogen used. The entire experiment was given a blanket application of phosphorus and potassium, but the rate of nitrogen was varied from 20 to 160 pounds of nitrogen per acre. The time of application was also varied. Rate, method, and time of application are given in Table II.

Table 2. Rate, Method, and Time of Application of Anhydrous Ammonia

Treatment No.	Rate of N lbs/A.	Method of Application	Time of Application
1	0		
2	20	Plowed down with moldboard	8-24-54
3	40	Plowed down with moldboard	8-24-54
4	80	Plowed down with moldboard	8-24-54
5	160	Plowed down with moldboard	8-24-54
6	20	Anhydrous ammonia applicator	10-29-54
7	40	Anhydrous ammonia applicator	10-29-54
8	80	Anhydrous ammonia applicator	10-29-54
9	160	Anhydrous ammonia applicator	10-29-54
10	20	Anhydrous ammonia applicator	3- 3-55
11	40	Anhydrous ammonia applicator	3- 3-55
12	80	Anhydrous ammonia applicator	3- 3-55
13	160	Anhydrous ammonia applicator	3- 3-55
14	20	Plowed down and with applicator	8-24-54 and 10-29-54
15	40	Plowed down and with applicator	8-24-54 and 10-29-54
16	80	Plowed down and with applicator	8-24-54 and 10-29-54
17	160	Plowed down and with applicator	8-24-54 and 10-29-54
18	20	Plowed down and with applicator	8-24-54 and 3- 3-55
19	40	Plowed down and with applicator	8-24-54 and 3- 3-55
20	80	Plowed down and with applicator	8-24-54 and 3- 3-55
21	160	Plowed down and with applicator	8-24-54 and 3- 3-55
22	20	Anhydrous ammonia applicator	10-29-54 and 3- 3-55
23	40	Anhydrous ammonia applicator	10-29-54 and 3- 3-55
24	80	Anhydrous ammonia applicator	10-29-54 and 3- 3-55
25	160	Anhydrous ammonia applicator	10-29-54 and 3- 3-55

Approximately 40 pounds per acre of K_2O was applied broadcast before seeding and 40 pounds per acre of P_2O_5 (0-20-0) was applied with the seed at planting. All plots received both K_2O and P_2O_5.

In cases where two times of application are recorded, the rates were split.

On August 24, 1954, anhydrous ammonia was plowed down with a 14-inch moldboard plow attached to a Ford tractor, Figure 1. The anhydrous ammonia tank was mounted on the tractor just behind the seat, two distribution hoses with short pieces of quarter inch pipe attached at the ends were dragged in the furrows just ahead of the moldboards. The rate of application was adjusted with a Fisher-Porter flowrater which was calibrated in pounds of nitrogen per hour. Knowledge of tractor speed was required for determining pounds of nitrogen applied per acre. The following formulas were used:

$$T = (3600/D_1)\ D_2$$

$$D_1 = 43560/W$$

43560 = Square feet per acre

W = Width of applicator in feet

3600 = Desired time in seconds to cover 1 acre

D_1 = Distance traveled to cover 1 acre

D_2 = Measured distance used to clock tractor

T = Time required to travel measured distance when operating 1 acre per hour

The fall application of ammonia was applied with an 8 foot anhydrous ammonia application, Figure 2, made by Gotcher Engineering and Manufacturing Company, Clarksdale, Mississippi. The rate of ammonia was measured with the same flowrater as that used in the plowdown application. This application was made 6 inches deep at 16 inch intervals just prior to seeding. The spring application was made with the same applicator that was used for the fall application. The rates of ammonia are listed in Table 2.

On October 29, 1954, Ponca wheat was seeded at the rate of 70 pounds

Figure I   Plowdown applicator

Figure II Anhydrous ammonia applicator

Figure III Diagram of field layout

West End

	Plowdown - Spring		Check		Border
	Plowdown		Fall - Spring		Check
40#	Spring	160#	Plowdown - Spring		Fall
	Plowdown - Fall		Fall		Plowdown - Fall
	Fall		Plowdown - Fall	20#	Fall - Spring
	Fall - Spring		Spring		Plowdown
	Plowdown - Fall		Plowdown		Spring
	Fall - Spring		Fall		Plowdown - Spring
160#	Fall		Fall - Spring		Plowdown - Fall
	Plowdown	40#	Plowdown - Fall		Fall
	Plowdown - Spring		Plowdown	80#	Spring
	Spring		Plowdown - Spring		Plowdown
	Plowdown - Spring		Spring		Plowdown - Spring
Rep	Dead Furrow	Rep	Back Furrow	Rep	Dead Furrow
III	Plowdown - Fall	II	Fall - Spring	I	Fall - Spring
20#	Plowdown		Plowdown - Fall		Plowdown
	Fall	20#	Plowdown - Spring		Plowdown - Spring
	Spring		Fall	160#	Fall
	Fall - Spring		Plowdown		Plowdown - Fall
	Plowdown - Fall		Spring		Spring
	Fall - Spring		Fall		Fall - Spring
80#	Spring		Plowdown - Spring		Plowdown - Fall
	Fall	80#	Spring		Plowdown - Spring
	Plowdown - Spring		Plowdown - Fall	40#	Fall
	Plowdown		Fall - Spring		Fall - Spring
	Check		Plowdown		Plowdown
	Border		Check		Spring

East End

per acre with a 13 x 7 grain drill. The wheat was drilled perpendicular to the plots so that the spring application of ammonia could be made at right angles to the rows of wheat.

Field Plot Design

The experiment was set up as a randomized block split-plot design with three blocks arbitrarily identified as I, II, and III. Each block consisted of four main plots and these were divided into six sub-plots, 200 feet long and eight feet wide. The main-plots were rates of nitrogen, while the sub-plots were time of nitrogen application. There were four check plots, one between each block and one at each end of the experiment, making a total of 76 plots. The four check plots cannot be analyzed statistically with the rest of the experiment, but may be used as a guide in determining the response to applied nitrogen. A diagram of the field layout is shown in Figure III.

Method of Harvest and Analysis of Grain

On June 17, 1955 an area from each plot 100 feet long and 7 feet wide was harvested with a 7 foot Massey Harris combine, Figure IV. The grain was caught in burlap bags, weighed, and sampled for protein determinations.

The samples were ground with a Wiley mill and dried to constant moisture. Protein determinations were made and results were adjusted to a 14 percent moisture basis. Nitrogen was determined by the Kjeldahl method. Percent nitrogen was multiplied by the factor 5.7 to obtain percent protein.

Figure IV Seven foot Massey Harris combine

Precipitation and Soil Moisture

Three sets of moisture samples were obtained, one in each block, five times during the growing season with Veihmeyer moisture sampling tubes. The samples were collected at twelve-inch intervals, with the exception of the first foot, which was sampled at six-inch intervals. They were placed in air tight moisture cans and transported to the laboratory for moisture percentage determinations. The moisture percentages in the soil at various dates throughout the season are shown in Appendix III.

A standard U. S. Weather Bureau rain gauge was placed near the experimental plots and measurements were taken after each rain. Precipitation in inches by ten day intervals are presented in Appendix II.

Note: A complete description of Ponca winter wheat is given in: "Ponca Winter Wheat," Agri. Exp. Sta. Bul. Kansas 354, Okla. B-380 (1952) by Laude, H. H. and Schlehuber, A. M., et al.

RESULTS AND DISCUSSION

Climatic and Soil Moisture Data

The precipitation at the experimental site from July 1954, to June 1955, is given in the Appendix, Table II. The precipitation was above average in October when the wheat was seeded, but during November when the stand was becoming established it was considerably below average. The precipitation was below average in March and April when the wheat was growing rapidly. It was slightly below average in May and considerably below average in April when the wheat was heading and ripening. The total annual rainfall was 8.90 inches below the long time average. Climatic conditions were favorable for wheat production as is indicated by the high yields.

Moisture equivalent and moisture percentages in the soil at various dates during the season are given in Appendix Table III. These data show that relatively good moisture conditions prevailed until the first part of April, then rains in May provided good moisture conditions until harvest.

Yields

The average grain yields are reported in Table (3), and a statistical summary of that data is given in Table (4). The statistical analysis indicates that rate of nitrogen and time of application had no significant influence on the yield of grain at the 5 percent level. The check plots averaged 28.6 bushels per acre which was slightly below the best

Table 3. Yields of wheat in bushels per acre (Avg. three replicates)

Rate of N lbs/acre	Time of Application: Plow-down	Fall	Spring	Plow-down-Fall	Plow-down-Spring	Fall-Spring	Avg.
20	28.4	27.6	30.4	28.7	30.2	29.9	29.2
40	28.5	29.8	26.9	28.7	27.3	29.1	28.4
80	28.5	28.2	29.4	26.6	30.8	28.6	28.7
160	26.2	25.1	26.1	26.0	29.9	27.0	26.7
Average	27.9	27.7	28.2	27.5	29.6	28.6	

28.6 Average yield of the four check plots.

For Rate -
Std. error of means = $\sqrt{24.34/3} = 2.85$
Std. error of differences between two means = $\sqrt{2(24.34/3} = 4.03$

For Time -
Std. error of means = $\sqrt{3.74/12} = .57$
Std. error of difference between two means $\sqrt{2(3.74/12} = .79$

Table 4. Statistical Summary of Wheat Yield Data

Source	D.F.	SS	M.S.	F
Main plots				
Rates	3	62.04	20.68	.849
Blocks	2	355.78	177.89	
Main plot error	6	146.03	24.34	
Subplots				
Time	5	45.08	5.02	1.342
Time x Rates	15	57.89	3.86	1.032
Subplot error	40	149.55	3.74	

The F test at the 5 percent level indicates no significant difference in rates or time of application.

treatment. This indicates that the soil was sufficiently high in nitrogen for maximum grain production.

Protein Content

The protein content of the grain was determined and the average protein percentages are reported in Table 5. A statistical summary of the protein data is given in Table 6.

The protein data were further broken down by the new multiple range test as is shown in Tables 7 and 8.

The analysis of variance, Table 6 shows that both variables, rate of nitrogen and time of application of nitrogen had significant effects on protein content of the grain. The protein content increased as the nitrogen levels were increased. The multiple range test, Table 7 shows that grain from plots which received 160 pounds of nitrogen was significantly higher in protein than grain from plots which received nitrogen at the following rates: 80, 40, and 20 pounds per acre. The grain from plots which received 80 pounds of nitrogen was significantly higher in protein than grain from plots which received 40 and 20 pounds of nitrogen per acre. There were no significant differences in protein content of grain from plots which received 40 and 20 pounds of nitrogen per acre.

The addition of nitrogen increased the protein content of the grain, even though the soil was sufficiently high in nitrogen for maximum grain production.

The multiple range test, Table 8, shows that the protein content of grain from plots which received nitrogen at the following times of application: plowdown, plowdown-fall, and fall, was significantly higher than grain from plots which received nitrogen during the spring and plowdown

Table 5. Protein Content of Grain (percent)

Rate of N lbs/acre	Time of Application						
	Plow-down	Fall	Spring	Plow-down-Fall	Plow down Spring	Fall-Spring	Avg.
20	14.40	14.62	13.88	14.62	14.18	14.19	14.32
40	14.39	14.43	14.03	14.69	14.00	14.53	14.35
80	15.01	15.17	14.32	14.91	14.79	15.05	14.87
160	15.59	15.85	15.24	15.39	14.67	15.32	15.34
Average	14.85	15.01	14.36	14.92	14.41	14.77	

13.74 Average percent protein content of the 4 check plots.

For Rate -
Std. error of means $\sqrt{.2753/3} = .30$
Std. error of difference between two means $= \sqrt{2(.2753)/3} = .74$

For Time -
Std. error of means $\sqrt{.2341/12} = .14$
Std. error of difference between two means $\sqrt{2(.2341)/12} = .19$

Table 6. Statistical Summary of Protein Percentage Data

Source	D.F.	SS	M.S.	F
Main plots				
Rates	3	12.4310	4.1655	15.13**
Blocks	2	15.9544	7.9772	
Main plot error	6	1.6518	.2753	
Subplots				
Time	5	4.3318	.8664	3.70**
Time x Rates	15	1.7774	.1185	
Subplot error	40	9.3643	.2341	

**Indicates significance at the one percent level of confidence.

Table 7. The New Multiple Range Test on Wheat Protein Percentage Data

Rate of N per acre	20	40	80	160
Average protein Percentage	14.32	14.35	14.87	15.34

Any two means not underlined by the same line are significantly different.

Any two means underlined by the same line are not significantly different (5 percent level)

Table 8. The New Multiple Range Test on Wheat Protein Percentage Data

Time of Application	Spring	Plow-down-Spring	Fall-Spring	Plow-down	Plow-down-Fall	Fall-Spring
	14.37	14.41	14.77	14.85	14.91	15.01

Any two means not underlined by the same line are significantly different.

Any two means underlined by the same line are not significantly different (5 percent level).

spring applications. It further shows that there is no significant difference between the following times of application: spring, plowdown-spring, and fall-spring. It is interesting to note that the spring application and any combination including it gave the lowest protein content of any of the times of application.

Test Weight of Grain

Test weights (weight per measured bushel) were determined on composites of replicates rather than on individual plots. The values are presented in Table 9. The effect of the nitrogen applications on test weight was very slight.

Table 9. Test Weight of Wheat Grain

Treatment	Pounds per Measured Bushel
Check	59
20 Plowdown	59
20 Fall	58
20 Spring	59
20 Plowdown - Fall	58
20 Plowdown - Spring	58
20 Fall - Spring	59
40 Plowdown	59
40 Fall	58
40 Spring	58
40 Plowdown - Fall	58
40 Plowdown - Spring	57
40 Fall - Spring	58
80 Plowdown	58
80 Fall	57
80 Spring	58
80 Plowdown - Fall	58
80 Plowdown - Spring	58
80 Fall - Spring	57
160 Plowdown	58
160 Fall	57
160 Spring	57
160 Plowdown - Fall	57
160 Plowdown - Spring	58
160 Fall - Spring	57

Treatments: Treatments are shown in pounds per acre of nitrogen. Determinations were made on composites of three replicates.

SUMMARY AND CONCLUSIONS

An experiment was conducted in Rogers County, Oklahoma on a Dennis silt loam to determine the most efficient time for applying anhydrous ammonia as a source of nitrogen for winter wheat, and to determine the nitrogen needs for maximum wheat production on this soil. From the results of this experiment, the following conclusions seem justifiable.

1. Neither rate nor time of application of nitrogen had any significant influence on the yield of grain.
2. The soil was sufficiently high in nitrogen for maximum grain production, as indicated by the high yields obtained on the check plots.
3. Addition of nitrogen increased the protein content of the grain, even though the soil was sufficiently high in nitrogen for maximum grain production.
4. Grain protein content increased with increasing levels of nitrogen application.
5. Spring application or any combination including it gave the lowest protein content of any of the times of application.

INTRODUCTION

PART II

Phosphorus deficiency is quite common in many soils of southeast Oklahoma. Field fertility trials have been conducted on such soils, however, little attention has been given to phosphate carriers and placement. The phosphorus was banded with the seed in most of the field fertility studies.

This study was conducted on Dennis silt loam under greenhouse conditions. The objectives were: (1) to determine the effect of nitrogen and phosphorus alone, and in combination on wheat forage yield, root development, and nitrogen and phosphorus content of the forage, (2) to determine the effect of placement of ammonium nitrate in relation to superphosphate on forage yield, nitrogen content, and phosphorus content of the forage, and (3) to determine the relative efficiency of ammonium phosphate and superphosphate as phosphate fertilizers for wheat.

REVIEW OF LITERATURE

Olsen, et al. (34) conducted a comprehensive series of field tests in the Rocky Mountain States in which they studied the relative effectiveness of different phosphatic fertilizers on calcareous soils. The results with the fertilizers tagged with radioactive phosphorus showed that water-insoluble materials such as dicalcium and tricalcium phosphate were relatively poorer sources of phosphorus than were the more water-soluble forms, such as monocalcium phosphate and monoammonium phosphate. Their comparisons with superphosphate and ammonium phosphate indicated that both materials supplied about equal amounts of phosphorus to all crops tested.

Experiments by Spear, et al. (44) on a calcareous Houston black clay of pH 8.1, showed that water-soluble forms such as normal or double superphosphate, monoammonium or monopotassium phosphate, and phosphoric acid "appeared to be outstanding sources of phosphorus." In contrast, dicalcium and fused tricalcium phosphate with low water solubility were "virtually useless," while ammoniated superphosphate was "intermediate" in usefulness. On a soil of low fertility and with a pH of 6.1 all of these same fertilizers were "utilized" two or three times more efficiently than on the calcareous soil.

Greenhouse tests by Martin, et al. (29) showed that ammoniation of superphosphate had relatively little effect upon the "chemically available" phosphate present, but high ammoniation greatly reduced the water-soluble phosphate in the material. On four acid soils, changes in the proportions of water-soluble phosphorus in the materials did not alter plant response. Results on two calcareous soils showed that light ammoniation of superphosphate did not reduce its availability to plants and that growth was related to the amount of "chemically available" phosphate applied. With high ammoniation, in which the water-soluble phosphorus was reduced to 32 percent of that in superphosphate, growth was proportionate to the amount of water-soluble phosphorus present and not to the citrate-soluble phosphorus.

Rogers (38) found no evidence that high solubility "greater than about 10 percent" was required in nitraphosphate for small grain, corn and cotton on soils of the southeastern part of the United States. He reported results which indicated that water-solubility was more important on soils extremely deficient in native phosphorus. Very limited tests in Iowa and Nebraska, however, suggested that the nitraphosphates of low water-solubility may be somewhat less effective on alkaline soils than the more soluble superphosphate. On acid soils of the southeast his comparison between nitraphosphate and concentrated superphosphate, showed the two materials to be equal in available phosphorus to corn, cotton, and small grain.

Lewis, Jordan, and Juve (25) studied the effects of certain cations and anions on phosphorus availability. In general, they found the salts of calcium, which have a common ion with most phosphate fertilizers, caused the greatest fixation of both fertilizer and soil phosphate. Sodium salts increased the availability of both fertilizer and soil phosphate. The magnesium salts were intermediate between calcium and sodium in the release of soil phosphate and fixation of fertilizer phosphate.

The anions, chloride, sulfate, and carbonate varied in their effects on availability of soil and fertilizer phosphate. In general, increasing the rate of salts decreased the availability of fertilizer and soil phosphate. Increasing the rate of sodium carbonate, however, increased both available soil and fertilizer phosphate.

Lorenz and Johnson (26) reported that ammonium fertilizers greatly increased potato yields over nitrate fertilizers. The physiologically acid ammonium sulfate effectively released native soil phosphate, whereas nitrogen from calcium nitrate and sodium nitrate did not. Response from ammonium nitrate was intermediate. They showed that if the phosphorus supply was enhanced by acidification with elemental sulfur and additions of large amounts of phosphatic fertilizers, good response to nitrate fertilizers could be expected.

Rennie and Mitchell (37) showed that additions of ammonium nitrate to two phosphate carriers, mono-ammonium phosphate and mono-calcium phosphate, gave no indication of any significant increase in wheat yield. However, they found that ammonium nitrate additions to the two phosphate carriers significantly increased the fertilizer phosphorus uptake by plants. They also showed that fertilizer phosphorus uptake from mono-ammonium phosphate was significantly higher than from mono-calcium phosphate. A lowering of the pH in the vicinity of the fertilizer, due to the addition of acid forming products such as ammonium nitrate, was suggested as a reason for this marked increase in availability.

Fudge (18) showed that acid forming fertilizers such as ammonium sulfate, ammonium nitrate, and urea caused a marked decrease in phosphate availability when applied to soils having pH values from 5.2 to 6.2. He found that physiologically basic fertilizers, sodium nitrate, calcium nitrate and calcium cyanamid caused an increase in phosphate availability. Calcium nitrate had about the same effect on acidity as sodium nitrate, however, phosphate was not as available on the plot receiving sodium nitrate. This was due to the fact that calcium furnished a quantity of base for uniting with phosphate. The compounds thus formed are not as soluble as the compounds formed when sodium is the base supplied.

In Alabama, Ensminger (16) made a study using ammo-phos (11-48-0). He found that this source of nitrogen actually reduced the yield of cotton on sandy soils. Other studies showed that the addition of lime to the mono-ammonium and di-ammonium phosphates increased the efficiency of the fertilizers.

Starostka and others (48) found that intermixtures of dicalcium phosphate with either ammonium sulfate, ammonium nitrate or potassium chloride significantly enhanced both alfalfa yield and phosphorus uptake over the dicalcium phosphate treatment alone on most soils studied. However, they did observe a decrease in both yield and phosphorus uptake on one of the soils.

Hall, et al, (19) in their study of superphosphate, ammoniated superphosphate, alpha tricalcium phosphate, dicalcium phosphate and calcium meta phosphate found that the phosphate absorbed by plants was affected somewhat by the source of phosphate. The absorption of phosphorus from dicalcium phosphate was lower than from any of the other sources on both low and high-phosphorus soils. On the high-phosphorus soil the absorption from alpha tricalcium phosphate was also relatively low. The absorption from calcium meta-phosphate, however, was very high. They found no consistent effect of source of phosphate on the total P_2O_5 content in the plants.

Data obtained by Dion, et al. (12) indicated a greater availability of phosphorus when it was applied in the form of mono-ammonium phosphate than when it was applied as mono-calcium phosphate or tricalcium phosphate. In every case, wheat plants treated with ammonium phosphate showed a significantly higher uptake of phosphorus than those treated with mono-calcium phosphate, or tri-calcium phosphate.

Woltz and others (53) found no significant difference in total growth or percentage content of phosphorus in tobacco plants as a result of applying ordinary or ammoniated superphosphate. An increase in rates of applied phosphorus (superphosphate and ammoniated phosphate) at all locations resulted in an increase in total growth, in amounts of phosphorus in the plant from the fertilizer, and in the amounts of phosphorus in the plant from the soil.

Mitchell, et al. (31) found no significant increase in wheat grain yield from plots receiving ammonium phosphate over those receiving superphosphate, however, the general trend indicated a more efficient utilization of phosphorus from ammonium phosphate than from superphosphate.

Results obtained by Mitchell (30) showed that 11-48-0 fertilizer gave larger wheat yield increases than those obtained when the same amount of phosphate was applied as 0-48-0. He stated that there is a possibility that the nature of the carrier (11-48-0) might have an influence on the availability of phosphorus to the plant. He felt that the differences in yield should not be attributed to the nitrogen carried in the 11-48-0.

In a placement test conducted by Mitchell (31) the most favorable responses resulted from placing both seed and fertilizer, ammonium phosphate or superphosphate, at a depth of 3 inches. Other placements were

(a) fertilizer placed 1 inch above the seed and (b) 1.5 inch beneath the seed, with the seed level at 3 inches.

Woltz, et al. (53) found no significant differences in total growth due to various fertilizer placements. Side-dressing did, however, result in a much smaller early growth, and in a lower utilization of fertilizer phosphorus than did banding or mixing in the row.

Olsen, et al. (34) showed that placement of fertilizer with a "rotiller" near the seed on sugar beets markedly increased the uptake of phosphorus compared to band placement at thinning time. In later stages of growth, however, the band placement supplied more phosphorus to the plants than the "rotiller" placement in a dry year, and about equal amounts in a wet year. Their placement studies with potatoes indicated more absorbed phosphorus from fertilizer placed 4 inches below the seed than from fertilizer placed 2 inches below the seed.

Greenhouse placement tests by Starostka and Hill (48) indicated that in most instances, additions of salts other than dicalcium phosphate in separate placement with dicalcium phosphate did not affect the Yield or phosphorus uptake of the crop significantly. However, they found the phosphate uptake to be significantly higher for intermixture applications over separate placements.

Stanford and Nelson (46), in their study on placement of phosphorus for corn found that placement of the fertilizer at seed depth and in bands on one or both sides of the seed generally resulted in a greater utilization of the applied phosphorus by the plant than placement in a single band over the level of the seed or in a single band 3 inches below the seed. Final grain yields showed no consistent differences between the methods of placement.

Data obtained by Eck (13) indicated that the immediate function of band applied fertilizer phosphorus is to give corn plants a good start. Residual soil phosphorus makes up the bulk of phosphorus used in growth and development of corn plants. A further indication was that superphosphate is a more desirable phosphate fertilizer source than calcium metaphosphate, especially when rapid initial growth and high phosphorus content at the early stages of growth are desired.

Nelson, et al. (32) found no significant differences due to placement on the final yield of either corn or cotton. However, placement influenced the pounds of phosphate absorbed from the fertilizer in both corn and cotton. Broadcast gave a relatively low total uptake compared to placement of fertilizer with the seed or in a band to the side or below the seed.

Pesek (36) found that either broadcasting or drilling the superphosphate or calcium meta-phosphate was an effective means of supplying additional phosphorus to established meadows; however, the drilling operation appeared to decrease the forage yields slightly. The plant absorption data for phosphorus showed that broadcasting was more effective than drilling as a method of applying calcium meta-phosphate.

Starostka, et al. (49) in their study of phosphorus placement found that band placement of superphosphate gave a significantly greater yield and greater phosphorus uptake than mixed placement. They also found the percentage of plant phosphorus derived from fertilizer was greater when superphosphate was banded than when it was mixed with the soil.

MATERIALS AND METHODS

The soil in this study has been classified as Dennis silt loam[1]. The soil was obtained from the Fred George farm located 2½ miles east of Porter, Oklahoma in the N.W. ¼, section 14, T. 16 N, R. 17E. in Wagoner County.

Soil Analysis

The soil analyses were made in the soil management laboratory at Oklahoma Agricultural and Mechanical College. All analyses, with the exception of mechanical analyses (24), nitrates (45), and available phosphorus (50) were made according to the methods outlined by Harper (21). The results of the soil analyses are shown in Table 10.

Greenhouse Procedure

In this study two-gallon, glazed, non-porous pots were used for the cultures. A sufficient quantity of soil was placed in each container so that the surface was within approximately two inches of the top of the pot. The weight of soil required per pot was 18 pounds per pot.

Treatment applications were made on October 24, 1955, with the exception of lime which had been applied two weeks previously and potassium which was added on January 15, 1956. The treatments in this study are shown in Table 11.

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[1]A description of the Dennis series is in Appendix Table I.

Table 10. Soil Analyses of Dennis Silt Loam

Analysis	Results
Mechanical Analysis	18.5 % Sand 69.0 % Silt 12.5% Clay
Soil Class	Silt Loam
Reaction (pH)	4.8
Nitrogen	.076%
Nitrates	6.0 lbs/A.
Organic Matter	1.06%
Available Phosphorus	38.0 lbs./A.
Total cation Exchange Capacity	8.49 m.e./100 grams
Total Exchangeable Bases	5.36 m.e./100 grams
Exchangeable K	.20 m.e./100 grams
Exchangeable Ca.	3.19 m.e./100 grams
Exchangeable Mg.	2.24 m.e./100 grams

Table 11. Fertilizer Treatments and Placements.

Treatment No.	Pounds/acre	Placement
1	Check	
2	300# NH_4NO_3	Banded 1" below and ½" to the side of the seed
3	400# Superphosphate	Banded 1" below and ½" to the side of the seed
4	400# Superphosphate plus 300# NH_4NO_3	Banded together 1" below and ½" to the side of the seed
5	400# Superphosphate plus 300# NH_4NO_3	Superphosphate banded 1" below and ½" to the side of the seed with NH_4NO_3 broadcast
6	400# Superphosphate plus 300# NH_4NO_3	Banded separate 1" below and ½" to the side of the seed
7	400# Ammo-phos	Banded 1" below and ½" to the side of the seed
8	400# Superphosphate plus 194# NH_4NO_3	Banded together 1" below and ½" to the side of the seed

Lime was uniformly incorporated with the soil at the rate of 3600 pounds per acre on the same series of treatments. This makes a total of sixteen treatments. 126 pounds of KCl per acre was added to all plots in the form of solution.

Concho wheat was seeded in a ring one inch below the surface and one inch from the wall of the container on October 24, 1955, however, due to a killing freeze, the pots were replanted November 15, 1955. Six seeds were planted in each pot. After the plants emerged, it was necessary to transplant some plants into pots where complete stands were not obtained. The purpose for planting only six seeds was to obtain equal spacings between plants. The pots were arranged in a randomized block design on a bench in the greenhouse. Forty eight pots were required as there were 16 treatments with three replications. The pots were rotated once each week within blocks. Tap water was used to water the plants throughout the growth period.

On December 19, 1955 the plants were moved into the cold room for a vernalization period of twenty-five days. Counts of the number of plants per pot containing three leaves were made 38 and 42 days after seeding. The number of plants per pot with tillers were counted 47 and 50 days after seeding. Counts were made of the total number of tillers per pot, 57, 71, and 84 days after seeding.

Sixty-seven days after planting, pictures were made of the vegetative growth of the wheat plants. All pictures were taken of the third replication.

On February 8, 1956 all the plants of the no lime series were harvested. The soil was washed from the roots in order to study both root development and distribution. Notes were taken on each individual pot. Tops and roots were separated and placed in a drying oven at 60°C. for 48 hours. Weights of both dry shoot and root material were taken. The vegetative material samples were then ground with a Wiley mill and stored in small glass containers. The samples were analyzed for phosphorus content according to the methods of Shelton and Harper (41), and for nitrogen content by the Kjeldahl method. All the data were analyzed statistically by the randomized block method reported by Snedecor (43).

The limed series was left until maturity. Yield and chemical analyses data will be taken but will not be presented here.

Note: A complete description of Concho winter wheat is given in: "Concho Winter Wheat," Okla. Agri. Exp. Sta. Bul. B-453 (1955), by Schlehuber, A. M. and Young, Jr., H. C.

RESULTS AND DISCUSSION

Results of 2 leaf counts, 38 and 42 days after seeding, and 5 tiller counts, 47, 50, 57, 71, and 84 days after seeding, are reported in Tables 12, 15, 18, 21, 24, 27, and 30 respectively. Analyses of variance of the counts, Tables 13, 16, 19, 22, 25, 28, and 31 indicate highly significant differences due to treatments at all counts. Multiple range tests for the respective counts are presented in Tables 14, 17, 20, 23, 26, 29, and 32. In all counts with the exception of the first (number of plants per pot with 3 leaves 38 days after planting) the respective multiple range tests show that treatments which received phosphorus had significantly more plants with 3 leaves, (Table 17), plants with tillers, (Tables 20 and 23) and tillers per pot (Tables 26, 29, and 32) than those which received no phosphorus. There were no significant differences due to lime, nitrogen fertilization, placement of nitrogen, nor source of phosphorus. At the first count, there was some indication that nitrogen alone was as good as some of the treatments which received phosphorus and that ammo-phos with lime was no better than treatments which did not receive phosphorus. Since these trends were not found in later counts, and the 3 leaf stage was just beginning at the time the count was made, it is felt that these differences may have been due to differences in stage of growth of the different plants rather than to treatments.

Table 12. Number of Plants per Pot with 3 Leaves, 38 Days after seeding. (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	.33	.00
2. N banded alone	.66	.00
3. P banded alone	2.33	2.66
4. P plus N banded together	3.00	2.00
5. P banded N broadcast	3.00	2.00
6. P plus N banded separate	3.00	2.00
7. Ammo-phos 16-20-0 banded	2.00	1.33
8. P plus N ratio 16-20-0 banded together	2.00	2.33

Std. error of Means $\sqrt{.95/3} = .56$

Std. error of difference between two means $\sqrt{2(.95)/3} = .79$

Table 13. Statistical Summary of Number of Plants per Pot With 3 Leaves, 38 Days After Seeding

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F. Test
Total	47	84.92		
Treatments	15	47.92	3.19	3.37**
Replications	2	18.04	9.02	
Error	20	18.96	.95	

**Indicates significance at the one percent level of confidence.

Table 14. Multiple Range Test on Number of Plants per Pot with 3 Leaves, 38 Days After Seeding

Treatment Number	1_L	2_L	1	2	7_L	7	8	4_L	5_L	6_L	3	8_L	3_L	5	6	4
Average Number of Plants with 3 Leaves	0	0	.33	.66	1.33	2.0	2.0	2.0	2.0	2.0	2.33	2.33	2.66	3.0	3.0	3.

L refers to the lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Table 15. Number of Plants per Pot with 3 Leaves, 42 Days after Seeding. (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	2.00	1.66
2. N banded alone	1.00	2.00
3. P banded alone	6.00	6.00
4. P + N banded together	6.00	6.00
5. P banded N broadcast	5.66	6.00
6. P ± N banded separate	6.00	5.00
7. Ammo-phos 16-20-9 banded	5.33	6.00
8. P + N ratio 16-20-0 banded	6.00	5.66

Std. error of means. $\sqrt{1.07/3} = .59$

Std. error of difference between two means. $\sqrt{2(1.07)3} = .84$

Table 16. Statistical Summary of Number of Plants per Pot with 3 Leaves, 42 Days After Seeding

Source of Variation	Degrees of Freedon	Sum of Squares	Mean Square	F Test
Total	47	182.48		
Treatments	15	159.81	10.65	9.95**
Replications	2	1.36	.68	
Error	20	21.31	1.07	

**Indicates significance at the one percent level of confidence.

Table 17. Multiple Range Test on Number of Plants per Pot with 3 Leaves, 42 Days After Seeding

Treatment Number	2	1_L	1	2_L	6_L	7	5	8_L	3	4	6	8	3_L	4_L	5_L	
Average Number of Plants with 3 Leaves	1.0	1.66	2.0	2.0	5.0	5.33	5.66	5.66	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6

L refers to the lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Table 18. Number of Plants per Pot with Tillers, 47 Days after Seeding. (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	0.00	0.00
2. N banded alone	0.00	0.00
3. P banded alone	3.33	2.66
4. P + N banded together	3.00	2.33
5. P banded N broadcast	2.66	2.33
6. P + N banded separate	2.00	2.33
7. Ammo-phos 16-20-0 banded	3.00	2.66
8. P + N ratio 16-20-0 banded	2.66	3.00

Std. error of means. $\sqrt{1.35/3} = .67$

Std. error of difference between two means. $\sqrt{2(1.35)/3} = .94$

Table 19. Statistical Summary of Number of Plants per Pot with Tillers, 47 Days After Seeding

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	47	130.0		
Treatments	15	68.6	4.57	3.39**
Replications	2	17.4	8.70	
Error	20	27.0	1.35	

**Indicates significance at the one percent level of confidence.

Table 20. Multiple Range Test on Number of Plants per Pot with Tillers, 47 Days After Seeding

Treatment Number	2_L	1_L	2	1	6	6_L	5_L	4_L	7_L	3_L	8	5	8_L	6	4	3
Average Number of Plants with Tillers	0.0	0.0	0.0	0.0	2.0	2.33	2.33	2.33	2.66	2.66	2.66	2.66	3.0	3.0	3.0	3.

L refers to the lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Table 21. Number of Plants per Pot with Tillers, 50 Days after Seeding. (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	0.00	0.00
2. N banded alone	0.00	0.00
3. P banded alone	5.33	5.33
4. P + N banded together	4.66	5.00
5. P banded N broadcast	5.33	4.33
6. P + N banded separate	4.66	5.00
7. Ammo-phos 16-20-0 banded	5.00	4.66
8. P + N ratio 16-20-0 banded	5.66	5.33

Std. error of means $\sqrt{.823/3} = .52$

Std. error of difference between two means $\sqrt{2(.823)/3} = .74$

Table 22. Statistical Summary of Number of Plants per Pot with Tillers, 50 Days After Seeding

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	47	250.48		
Treatments	15	232.48	15.50	18.83**
Replications	2	1.54	.77	
Error	20	16.46	.823	

**Indicates significance at the one percent level of confidence.

Table 23. Multiple Range Test on Number of Plants per Pot with Tillers, 50 Days After Seeding

Treatment Number	1	2	1_L	2_L	5_L	4	6	7_L	7	4_L	6_L	3	6	3_L	8_L	8
Average Number of Plants with Tillers	0	0	0	0	4.33	4.66	4.66	4.66	5.0	5.0	5.0	5.33	5.33	5.33	5.33	5.

L refers to the lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Table 24. Total Number of Tillers per Pot, 57 Days After Seeding. (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	0.00	0.33
2. N banded alone	0.00	0.00
3. P banded alone	20.33	17.33
4. P + N banded together	16.66	17.33
5. P banded N broadcast	17.66	16.66
6. P + N banded separate	16.33	16.00
7. Ammo-phos 16-20-0 banded	17.33	15.66
8. P + N ratio 16-20-0 banded	16.66	16.66

Std. error of means $\sqrt{7.53/3} = 1.58$

Std. error of difference between two means $\sqrt{2(7.53)/3} = 2.24$

Table 25. Statistical Summary of Total Number of Tillers per Pot, 57 Days After Seeding

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	47	2843.31		
Treatments	15	2639.31	175.95	23.36**
Replications	2	53.37	26.68	
Error	20	150.63	7.53	

**Indicates significance at the one percent level of confidence.

Table 26. Multiple Range Test on the Total Number of Tillers per Pot, 57 Days After Seeding

Treatment Number	1	2	2_L	1_L	7_L	6_L	6	4	8	5_L	8_L	7	3_L	4_L	5	3
Average Number of Tillers per Pot	0.0	0.0	0.0	.33	15.66	16.0	16.33	16.66	16.66	16.66	16.66	17.33	17.33	17.33	17.66	20

L refers to the lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Table 27. Total Number of Tillers per Pot, 71 Days After Seeding, (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	5.33	4.66
2. N banded alone	2.66	3.66
3. P banded alone	37.33	35.66
4. P + N banded together	34.00	35.66
5. P banded N broadcast	34.00	36.00
6. P + N banded separate	35.66	30.33
7. Ammo-phos 16-20-0 banded	34.66	33.0
8. P + N Ratio 16-20-0 banded	36.00	37.66

Std. error of means $\sqrt{29.72/3} = 3.14$

Std. error of difference between two means $\sqrt{2(29.79)/3} = 4.46$

Table 28. Statistical Summary of Total Number of Tillers per Pot, 71 Days After Seeding

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	47	9357.48		
Treatments	15	8746.28	583.09	19.62**
Replications	2	16.79	8.29	
Error	20	594.41	29.72	

**Indicates significance at the one percent level of confidence.

Table 29. Multiple Range Test on the Total Number of Tillers per Pot, 71 Days After Seeding

Treatment Number	2	2_L	1_L	1	6_L	7_L	4	5	7	6	3_L	4_L	5_L	8	3	8
Average Number of Tillers per Pot	2.66	3.66	4.66	5.33	30.33	33.0	34.0	34.0	34.66	35.66	35.66	35.66	36.0	36.0	37.33	37

L refers to the lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Table 30. Total Number of Tillers per Pot, 84 Days After Seeding. (Average of 3 Replicates)

Treatment and No.	No Lime	Lime
1. Check	7.66	7.00
2. N banded alone	8.33	9.00
3. P banded alone	44.33	37.66
4. P + N banded together	42.33	42.00
5. P banded N broadcast	40.66	40.33
6. P + N banded separate	41.00	37.33
7. Ammo-phos 16-20-0 banded	38.33	38.00
8. P + N ratio 16-20-0 banded	41.33	40.66

Std. error of means $\sqrt{43.42/3} = 3.80$

Std. error of difference between two means $\sqrt{2(43.42)/3} = 5.38$

Table 31. Statistical Summary of Total Number of Tillers per Pot, 84 Days After Seeding

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	47	10531.00		
Treatments	15	9565.66	637.71	14.69**
Replications	2	96.87	48.43	
Error	20	868.47	43.42	

**Indicates significance at the one percent level of confidence.

Table 32. Multiple Range Test on the Total Number of Tillers per Pot, 84 Days After Seeding

Treatment Number	1_L	1	2	2_L	6_L	3_L	7_L	7	5_L	5	8_L	6	8	4_L	4	3
Average Number of Tillers per Pot	7.0	7.66	8.33	9.0	37.33	37.66	38.0	38.33	40.33	40.66	40.66	41.0	41.33	42.0	42.33	44.

L refers to lime series.
Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level)

Pictures of the vegetative growth of the wheat plants, Figures V through VII, show the influence of different treatments. The most striking differences were between the no phosphorus and the phosphorus treatments. Additions of lime did not effect the vegetative growth of the wheat.

Forage yields are reported in Table 33. The analysis of variance, Table 34, indicates a highly significant difference in forage yields due to the different treatments. The multiple range test, Table 35, shows that significantly more forage was produced by treatments which contained phosphorus than by those which did not contain phosphorus.

The ammo-phos and ammo-phos ratio treatments (64 lbs. N, 80 lbs. P_2O_5/A.) yielded significantly more than treatment 4 (100 lbs. N, 80 lbs. of P_2O_5/A. banded together) but did not yield different from phosphorus alone nor from the other phosphorus plus nitrogen treatments. This difference may be due to nitrogen rate, that is, the 100 pound nitrogen rate yielded less than the 64 pound rate but not significantly different from the zero nitrogen rate. It is believed though that this may be a one-in-twenty happenstance rather than a true difference since it did not show up in other placements nor in other data, (counts and root yields).

Root yields are presented in Table 36. The analysis of variance, Table 37, indicates a highly significant difference in root yields due to the different treatments. The multiple range test, Table 38, shows that significantly higher root yields were produced by treatments which received phosphorus than by those which did not receive phosphorus. There were no significant differences due to nitrogen fertilization, placement of nitrogen, nor source of phosphorus.

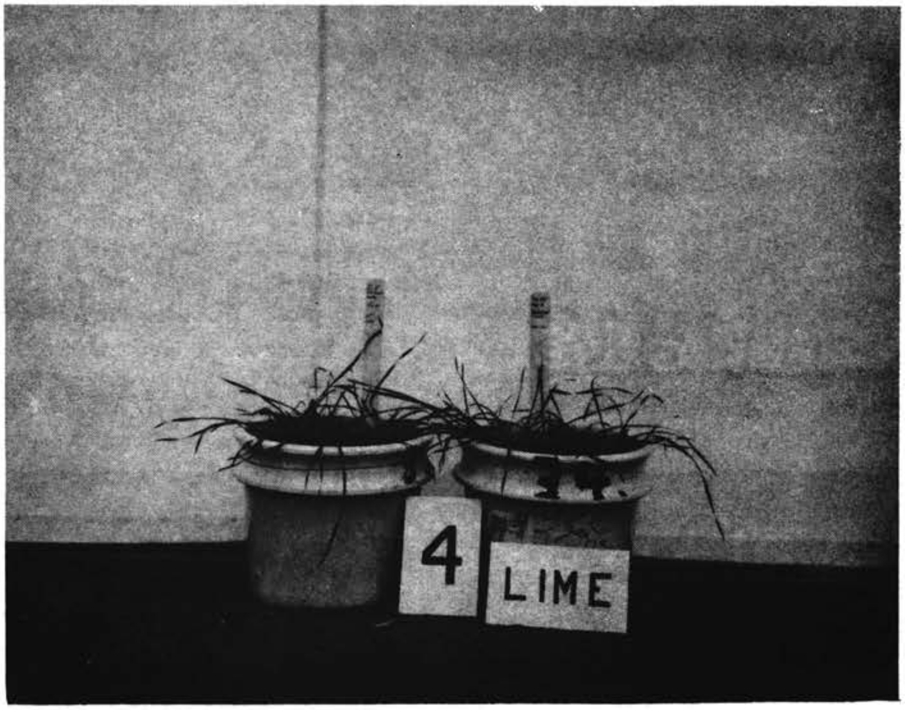

Figure V Effect of lime on growth of wheat. 66 days after seeding

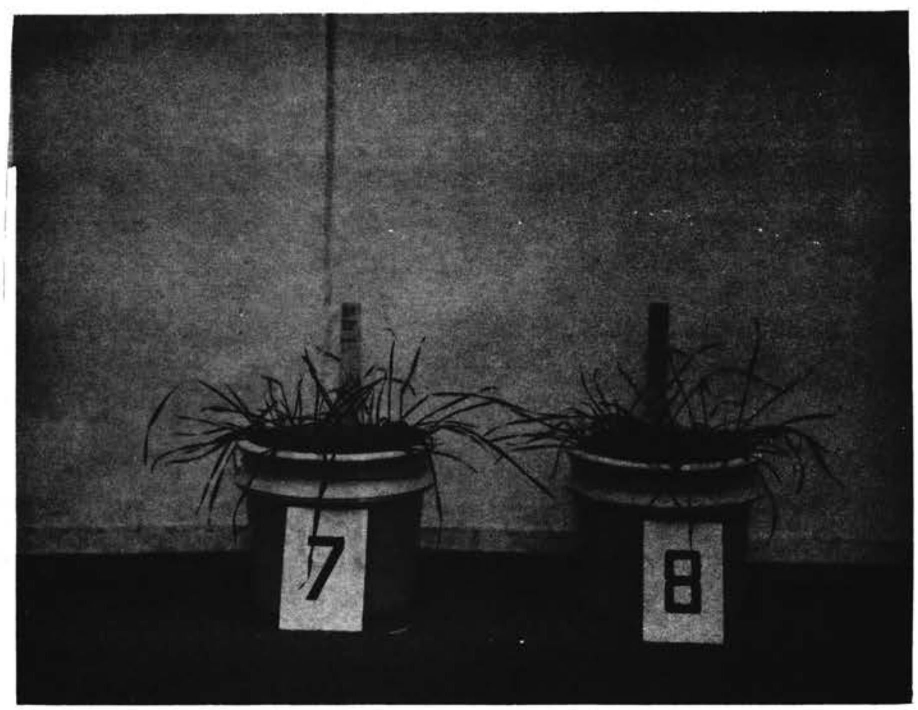

Figure VI Effect of ammo-phos (7) compared with nitrogen plus phosphorus (8) on growth of wheat. 66 days after seeding

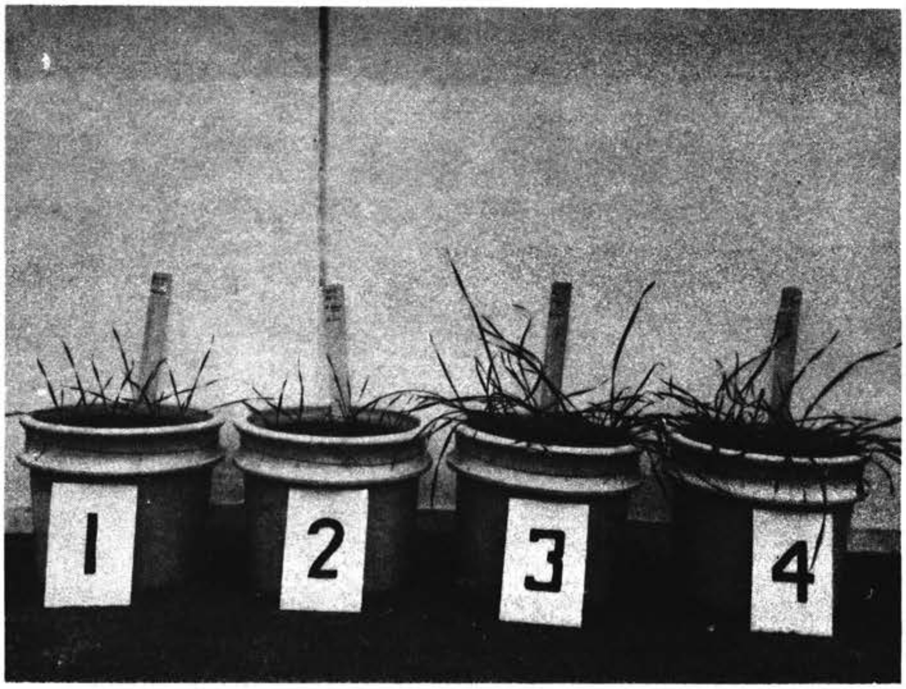

Figure VII A comparison of the check treatment (1) with nitrogen alone (2), phosphorus alone (3), and phosphorus plus nitrogen (4) on growth of wheat, 66 days after seeding

Table 33. Forage Yields of Wheat (gms. dry wt./pot)

Treatment No.	Rep. I	Rep. II	Rep. III	Total	Average
1	0.98	0.87	0.80	2.65	0.88
2	0.89	0.60	0.55	2.04	0.68
3	6.19	6.70	4.43	17.32	5.77
4	6.02	5.87	4.01	15.90	5.30
5	7.51	5.80	5.79	19.10	6.37
6	6.67	7.16	4.71	18.54	6.18
7	6.63	7.39	5.57	19.59	6.53
8	7.55	6.26	6.20	20.01	6.67
Total	42.44	40.65	32.06	115.15	

Std. error of means $\sqrt{.42/3} = .37$.

Std. error of difference between two means $\sqrt{2(.42)/3} = .50$

Table 34. Statistical Summary of Wheat Forage Yields

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	23	146.67		
Treatment	7	133.08	19.01	45.26**
Replications	2	7.70	3.83	
Error	14	5.89	.42	

**Indicates significance at the one percent level of confidence.

Table 35. Multiple Range Test of Pooled Means of Wheat Forage Yields

Treatment Number	2	1	4	3	6	5	7	8
Average Yield	0.68	0.88	5.30	5.77	6.18	6.37	6.53	6.67

Any two means not underlined by the same line are significantly different.
Any two lines underlined by the same line are not significantly different. (Five percent level)

Table 36. Yield of Roots (gms. dry wt./pot)

Treatment Number	Rep. I	Rep. II	Rep. III	Total	Average
1	0.66	0.76	1.03	2.45	0.82
2	0.79	0.47	0.72	1.98	0.60
3	4.58	2.78	2.99	10.35	3.45
4	6.18	2.32	2.38	10.88	3.63
5	4.33	2.43	2.44	9.20	3.07
6	3.09	3.79	1.83	8.71	2.90
7	3.95	3.01	3.08	10.04	3.35
8	2.38	2.52	3.47	8.37	2.79
Total	25.96	18.08	17.94	61.98	

Std. error of means $\sqrt{.86/3} = .53$

Std. error of difference between two means $\sqrt{2(.86)/3} = .75$

Table 37. Statistical Summary of Root Yields

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	23	46.03		
Treatment	7	28.87	7.12	8.28**
Replications	2	5.27	2.63	3.05
Error	14	11.98	.86	

**Indicates significance at the one percent level of confidence.

Table 38. Multiple Range Test of Pooled Means of Root Yields

Treatment Number	2	1	8	6	5	7	3	4
Average Yields	0.60	.82	2.79	2.90	3.07	3.35	3.45	3.63

Any two lines not underlined by the same line are significantly different.
Any two lines underlined by the same line are not significantly different. (Five percent level).

Phosphorus uptake data are presented in Table 39. The analysis of variance, Table 40, indicates a highly significant difference in phosphorus uptake due to the different treatments. The multiple range tests, Table 41, shows that forage from treatments 3 through 8, all of which received phosphorus, contained significantly more phosphorus than the forage from treatments 1 and 2 (check and nitrogen alone respectively). There were no significant differences in phosphorus uptake due to nitrogen fertilization, placement of nitrogen, nor source of phosphorus.

Nitrogen uptake data are presented in Table 42. The analysis of variance, Table 43, shows a highly significant difference in nitrogen uptake due to the various treatments. The multiple range test, Table 44, indicates that significantly more nitrogen was removed per pot from treatments which contained phosphorus than from those which did not contain phosphorus. There were no significant differences due to placement of nitrogen, nor source of phosphorus. With the exception of treatment 4 (100 lbs. N, 80 lbs. of P_2O_5/A.), the nitrogen uptake by plants was greater in all treatments which received both nitrogen and phosphorus, than in treatment 3 (phosphorus alone). Nitrogen uptake was higher from phosphorus alone than from nitrogen alone due to the greater amount of growth obtained from phosphorus alone. Phosphorus plus nitrogen banded together (treatment 4) did not significantly increase nitrogen uptake over phosphorus alone (treatment 3). This may be due to the greater amount of forage growth obtained from phosphorus alone. This also indicates that the soil nitrogen supply was not critical up to this stage of development.

Shoot/root ratios are presented in Table 45. The data indicate a higher shoot/root ratio from treatments receiving both phosphorus and

Table 39. Weight of Phosphorus in the Wheat Forage (mgms./pot)

Treatment Number	Rep. I	Rep. II	Rep. III	Total	Average
1	2.0	2.0	1.5	5.5	1.8
2	1.9	1.1	1.0	4.0	1.3
3	13.0	23.9	9.3	46.2	15.4
4	14.3	24.4	16.6	55.3	18.4
5	18.9	20.3	13.4	52.6	17.5
6	19.9	15.9	18.8	54.6	18.3
7	23.7	21.7	19.3	64.7	21.5
8	22.2	19.7	18.9	60.8	20.2
Total	115.9	129.0	98.8	343.8	

Std. error of means $\sqrt{11.12/3} = 1.93$

Std. error of difference between two means $\sqrt{2(11.12)/3} = 2.72$

Table 40. Statistical Summary of Weight of Phosphorus in the Wheat Forage

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	23	1590.48		
Treatment	7	1367.04	195.29	17.56**
Replications	2	67.81	33.91	3.05
Error	14	155.63	11.12	

**Indicates Significance at the one percent level of confidence.

Table 41. Multiple Range Test on Weight of Phosphorus in the Wheat Forage

Treatment Number	2	1	3	5	6	4	8	7
Average Mg. of P.	1.3	1.8	15.4	17.5	18.3	18.4	20.2	21.5

Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level).

Table 42. Weight of Nitrogen in the Wheat Forage. (mgms/pot)

Treatment Number	Rep. I	Rep. II	Rep. III	Total	Average
1	23.6	25.8	22.9	72.4	24.4
2	25.3	17.1	16.1	58.4	19.5
3	120.1	154.8	79.7	354.6	118.2
4	146.3	181.4	120.3	447.9	149.3
5	179.4	215.5	130.9	525.9	175.3
6	208.0	171.7	160.4	540.1	180.0
7	195.6	211.4	154.9	561.8	187.3
8	193.3	176.5	171.8	541.6	180.5
Total	1091.6	1154.1	857.0	3102.7	

Std. error of means $\sqrt{458.73/3} = 12.03$

Std. error of difference between two means $\sqrt{2(458.73)/3} = 17.05$

Table 43. Statistical Summary of Weight of Nitrogen in the Wheat Forage

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Test
Total	23	114503.75		
Treatments	7	102948.49	14706.93	3260.41**
Replications	2	5133.02	2566.56	
Error	14	6422.24	458.73	

**Indicates significance at the one percent level of confidence.

Table 44. Multiple Range Test of Weight of Nitrogen in the Wheat Forage.

Treatment Number	2	1	3	4	5	6	8	7
Average Mg. of N	19.5	24.4	118.2	149.3	175.3	180.0	180.5	187.3

Any two means not underlined by the same line are significantly different.
Any two means underlined by the same line are not significantly different. (Five percent level).

Table 45. Weight of Forage and Roots. (Gms./pot) Showing the Ratio. (Average of three replicates)

Treatment Number	Forage	Root	Root-Shoot Ratio
1	0.88	0.82	1:1.07
2	0.67	0.60	1:1.13
3	5.77	3.45	1:1.67
4	5.30	2.63	1:2.01
5	6.37	3.07	1:2.07
6	6.18	2.90	1:2.13
7	6.53	3.35	1:1.95
8	6.67	2.97	1:2.39

nitrogen than from treatments receiving no phosphorus. The shoot/root ratios of the nitrogen alone treatment and the check treatment are very similar. Phosphorus alone shows a higher shoot/root ratio than the no phosphorus treatments, however, not as high a ratio as the treatments receiving both phosphorus and nitrogen.

Plants from all treatments were examined for patterns of root distribution when the soil was washed from the roots. Root concentrations were observed in the phosphate fertilizer zones of all treatments which received both phosphorus and nitrogen. There appeared to be no root concentration in the phosphate fertilizer zone of the phosphorus alone treatment. Zones of root concentration were not found in the nitrogen alone and check treatments. Pictures of the roots are shown in Figures VIII through XI.

The phosphorus alone treatment produced a good root system; and the roots were more evenly distributed throughout the pots than were the roots from the treatments which received both phosphorus and nitrogen. The check and nitrogen alone treatments produced small root systems, and no concentrations of roots were observed.

Figure VIII Effect of check (1) compared with nitrogen alone (2), 84 days after seeding on root development of wheat

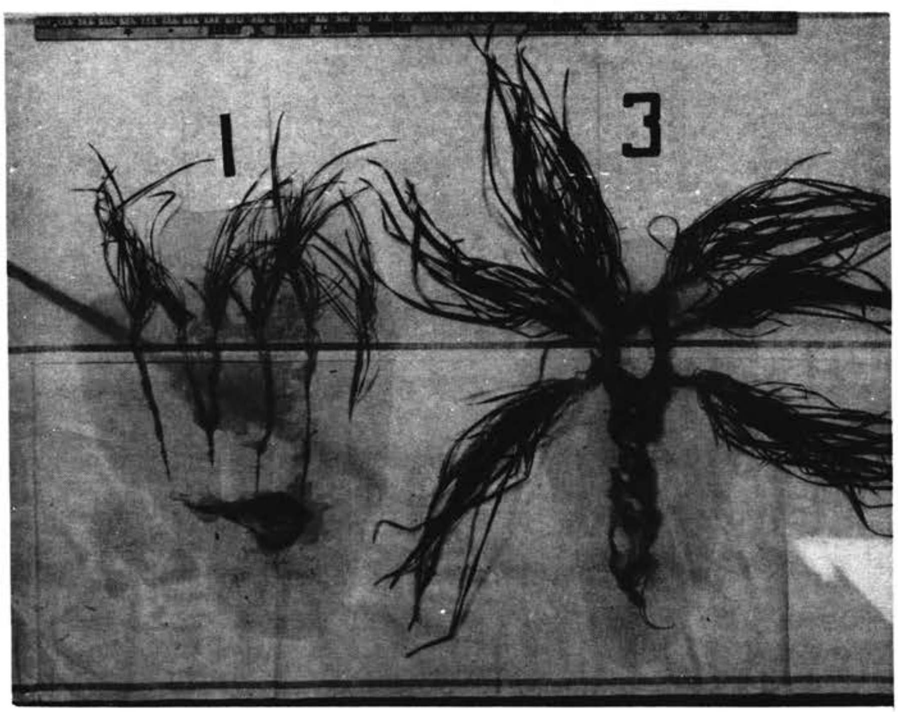

Figure IX Effect of check (1) compared with phosphorus alone (3), 84 days after seeding on root development of wheat

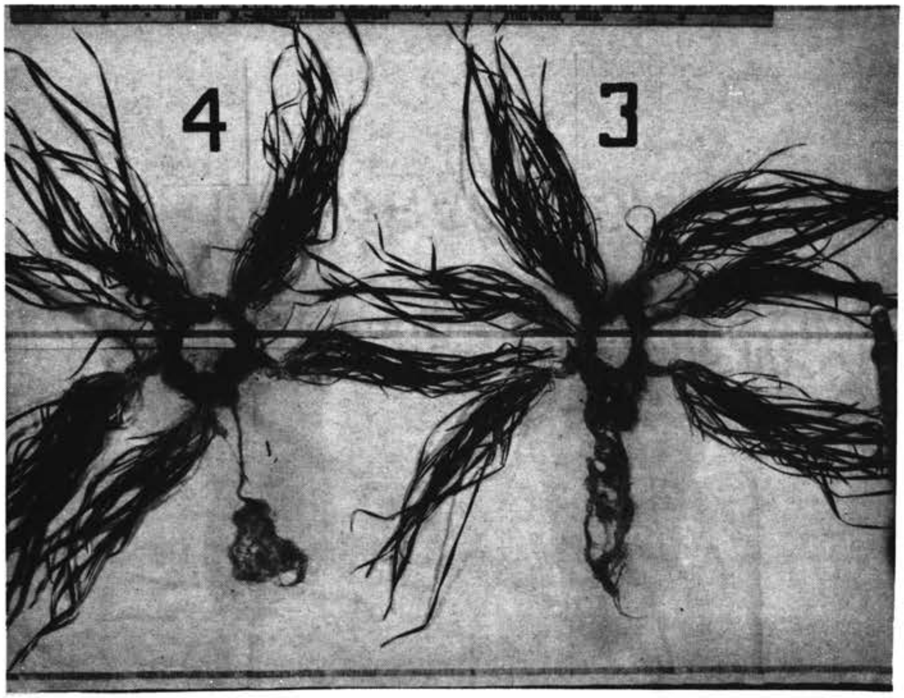

Figure X Effect of phosphorus alone (3) compared with phosphorus plus nigrogen (4), 84 days after seeding on root development of wheat

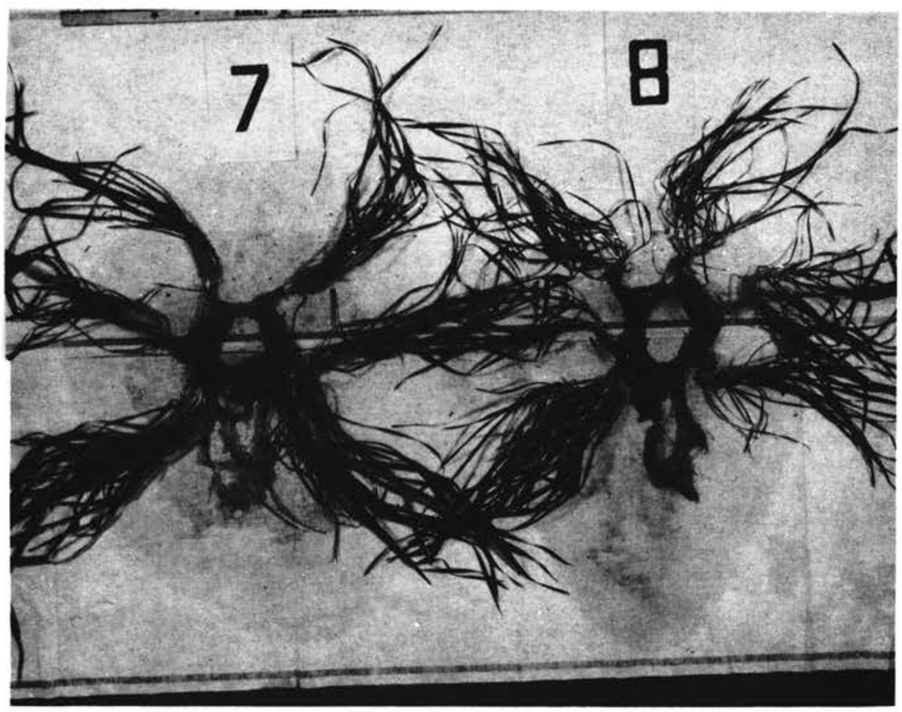

Figure XI Effect of ammo-phos (7) compared with nitrogen plus phosphorus ratio (8), 84 days after seeding on root development of wheat

Observations of the phosphorus alone treatment in the limed series, which was left until maturity, indicated that the soil did not contain enough available soil nitrogen for maximum wheat production. This was indicated by a definite yellowing of the wheat plants 91 days after seeding. The plants which received this treatment did not joint as did the plants which received both nitrogen and phosphorus.

SUMMARY AND CONCLUSIONS

An experiment was conducted on Dennis silt loam under greenhouse conditions to study the effect of nitrogen fertilization, placement of nitrogen, and phosphorus source on the availability of phosphorus to winter wheat.

The results of this study may be summarized as follows:

1. Nitrogen alone had no significant effect on wheat growth, nitrogen uptake, nor phosphorus uptake.
2. Phosphorus alone significantly increased wheat growth and nitrogen and phosphorus uptake. It was as effective as a combination of nitrogen and phosphorus in all measurements except nitrogen uptake.
3. Placement of nitrogen had no effect on availability of phosphorus to wheat.
4. There were no significant differences due to phosphorus source, (ammonium phosphate vs. superphosphate).
5. Lime had no significant effect on wheat growth in this experiment.
6. Though soil nitrogen did not limit plant growth up until the time of the vegetative harvest, observations of the limed series indicated that it was not adequate for maximum grain yields.

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A P P E N D I X

Appendix Table I. The General Characteristics of Dennis Silt Loam

A_1	0-11"	Dark-grayish-brown silt loam which is medium granular; friable; permeable; pores and worm casts are numerous. Reaction is strongly acid, pH 4.9; grades to horizon beneath
A_3	11-17"	Dark-grayish-brown light silty clay loam with a few, faint brown specks which are strongly granular; friable; and somewhat hard when dry. This is permeable and has many worm holes and a number of round black concretions. Reaction is strongly acid, pH 5.0; grades to horizon beneath.
B_1	17-24"	Grayish-brown light clay with common medium and fine, distinct yellowish-brown mottles; subangular blocky; firm, slowly permeable; fine black concretions abundant. Reaction is strongly acid; grades to layer beneath.
B_2-1	24-32"	Light-yellowish-brown light clay with many prominent brownish-yellow mottles; subangular blocky; firm; slowly permeable; fine black concretions and chips of weathered siltstones. Reaction medium acid; grades to horizon beneath.
B_{2-2}	32-42"	Light-brownish-gray clay with numerous yellowish-brown mottles; weak subangular blocky; firm; slowly permeable; numerous coarse black concretions with a few chips of siltstone and sandstone; vertical streaks of accretionary iron. Reaction medium acid; grades to horizon beneath.
B_{3C}	42-54"	Light-brownish-gray clay with many distinct, coarse yellowish-brown mottles; weak blocky; very firm; very slowly permeable; coarse black vertical streaks of accretionary iron numerous; peds coated with dark-grayish-brown films; reaction medium acid; grades to horizon beneath.
C	54"+	Yellowish-brown firm clay shale or clay beds.

Appendix Table II. Precipitation in Inches by 10 Day Intervals at Experimental Site (July 1, 1954-June 30,1955)

Days	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1-10		1.26	1.20	1.14	.40			.48		1.40	1.10	.95
11-20		3.80	.03	.87		1.00	.72	1.72	.57	.18	1.60	.80
21-31	.73	.10	1.22	2.53		2.75			1.60		2.00	
Total	.73	5.16	2.45	4.54	.40	3.75	.72	2.20	2.17	1.58	4.70	1.75
Avg.	2.96	3.43	3.8	3.71	2.1	1.78	2.28	1.32	2.59	4.05	5.15	5.17
Annual (1954-1955)												30.12
Avg. Annual												39.02

July through October data were taken from Claremore weather station.

November through June data were taken at the experimental site, long time data from Claremore weather station.

Appendix Table III. Moisture Percentages in the Soil at Various Dates Throughout the Season

Date and Stage of Plant Growth		Soil Depth, Inches						
		0-6	6-12	12-24	24-36	36-48	48-60	60-72
8-24-54	At plowing time	11.75	12.47	16.22	19.65	20.26	19.09	18.07
10-29-54	At planting time	20.70	20.13	20.05	22.26	19.36	18.13	18.94
12-22-54		14.89	11.60	19.43	21.76	21.19	19.42	19.67
3- 3-55	At spring application	20.09	19.29	21.90	26.56	20.46	17.34	16.35
4-18-55		10.79	12.49	17.89	19.46	16.68	15.95	16.50
6-17-55	At harvest time	15.79	14.78	15.36	19.05	18.47	20.39	17.04

VITA

Glennis Owen Boatwright

Candidate for the Degree of

Master of Science

Thesis: I. EFFECT OF TIME AND RATE OF APPLICATION OF ANHYDROUS AMMONIA ON YIELD AND PROTEIN CONTENT OF WINTER WHEAT

II. EFFECT OF NITROGEN FERTILIZATION, PLACEMENT OF NITROGEN, AND PHOSPHORUS SOURCE ON THE AVAILABILITY OF PHOSPHORUS TO WINTER WHEAT

Major Field: Soils

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