EVALUATION OF SOLID UREA FERTILIZER AS A SOURCE OF NITROGEN FOR WHEAT

by

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B.S.A.En., Central Luzon State University
Philippines, 1961

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

Approved by:

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INTRODUCTION

Wheat is the world's most valuable grain crop. It is superior to any other crop for human food in many respects. A reason for its superiority is its relatively high protein content.

The United States produces approximately one-fifth of the world's wheat. Of this production, Kansas produces one-fifth, a feat marking her as the leading wheat state in the nation. The average yield in Kansas in 1963 was about 20 bushels per acre and in 1964 was about 24 bushels per acre. These yields are considerably lower than those expected when yields at experiment fields and stations are considered.

An adequate supply of nitrogen in the soil is necessary to increase yields and raise high quality wheat. On the other hand, an excess of this nutrient may lead to excessive vegetative growth, lodging, depressed yields, low quality grain, and a low resistance to disease.

Earlier experimental work has shown that nitrogen is the limiting nutritional factor in many of the wheat producing areas of the state. Visual nitrogen deficiency symptoms such as yellowed plants, low test weights, and a high carbohydrate content of the grain (yellow berry) lend support to this statement. In order to overcome the shortage of this element, Kansas wheat producers are providing an ever increasing market for nitrogen fertilizers. Urea is one of the carriers being used in increasing amounts. The tonnage of urea sold in Kansas has increased from 12,000 tons in 1961-1962 to 24,500 tons in 1964-1965.

Urea is a desirable nitrogenous fertilizer for wheat. It has excellent physical properties in the form of free flowing prills, it is readily available to plants, completely water soluble, and contains the highest percentage of nitrogen of any solid carrier. When urea is applied to the soil, it is rapidly hydrolyzed by soil urease to ammonium and carbon dioxide. The resulting ammonium ions are adsorbed by the soil colloids and are thereby less susceptible to leaching than are nitrate ions.

Several factors are believed to influence the utilization of urea by plants. Some of these are available moisture, soil and air temperature, and probably method and time of application.

With the preceding thoughts in mind, this study was formulated with the following objectives:

1. To determine the effectiveness of solid urea as a nitrogen source for wheat.
2. To compare yield responses and quality factors arising from the application of urea with those obtained from equivalent applications of nitrogen as ammonium nitrate.
3. To compare the effectiveness of different dates of urea top dressing.

LITERATURE REVIEW

To acquire a better appreciation of the use of solid urea as a nitrogen carrier, it is imperative to review the properties, transformation, and utilization of urea.

Historically, urea is known as the chief excretory product of nitrogen in mammals and is excreted in the urine. In 1912, urea was synthesized from ammonia and phosgene by Davey, though Regnault is considered to be the first to have prepared urea by this reaction. In 1935, the first production of solid synthetic urea began in the United States (4). Since then, it has gained importance as a nitrogenous fertilizer material. Other names applied to urea include carbamide or amide of carbonic acid.

Urea has a nitrogen content of 46.65 percent, a melting point of 269° F., and is very water soluble. At 30° C., 133 g of urea (compared with 242 g of ammonium nitrate and 78 g of ammonium sulfate) dissolve in 100 ml of water. Urea and ammonium nitrate mutually enhance each others solubilities. At 30° C., 100 ml of water will dissolve a maximum of 719 g urea and 845 g of ammonium nitrate (22). Biuret is formed when urea is heated to temperatures above its melting point. At 140-170° C., the chief product is biuret formed from two molecules of urea by elimination of ammonia:

$$2CO(NH_2)_2 + \text{heat} \longrightarrow NH(CONH_2)_2 + NH_3$$

Biuret is toxic to some plants in relatively small amounts especially when biuret-containing urea is applied as foliar sprays. Urea containing 1-1.5 percent biuret can be expected to present no problem for soil applications. However, it is believed that heavy rates banded in direct contact with or near the seed may produce damaging effects on germination or seedling growth.

When applied to the soil, urea is rapidly taken into solution by the soil moisture. Hydrolysis to ammonium carbonate can result through the reaction:

$$CO(NH_2)_2 + 2H_2O \rightleftharpoons (NH_4)_2CO_3$$

Further hydrolysis to ammonia and carbon dioxide occurs via the reaction:

$$(NH_4)_2CO_3 \rightleftharpoons CO_2 + 2NH_3 + H_2O$$

The first reaction above is primarily activated by the enzyme urease (34). Pasteur was the first to recognize that the transformation of urea to ammonia is brought about by the living organism, Torula ammoniacale. But some organisms belonging to most families of bacteria, actinomyces, and fungi are also capable of decomposing urea. The optimum temperature for the action of these microorganisms is about 30° C. (27).

In a study employing lysimeter, field and laboratory techniques, it was determined that the hydrolysis of urea in soils is due to enzyme action as hydrolysis was shown to occur in the absence of microorganisms (25). The transformation of urea is brought about by a wide variety of microorganisms, but there is some evidence that ammonia can be produced from urea in soils treated with toluene and therefore devoid of living microorganisms (46).

Conrad published a series of papers on the hydrolysis of urea (10, 11, 12, 13, 14). He reported that the rate of hydrolysis of urea in the soils sterilized with toluene was only slightly lower than in soils which had not been treated with toluene (10). Murphy (39) in a somewhat similar study on two different types of Missouri soils obtained analogous results.

The action of nitrifying bacteria results in the oxidation of ammonium nitrogen to nitrate under favorable soil conditions. The immediate effect of urea hydrolysis on the soil is alkaline, but the nitrification of the ammonium ion results in the formation of an acid residue, making the soil slightly acidic (7). Increasing the soil temperature up to 30° C. increases the rate of urea hydrolysis. Investigations have shown, however, that urea completely hydrolyzed to ammonia within 4 days at temperatures above 39° F. (25, 42).

Gibson (23) investigated the decomposition of urea in 59 soil samples of extremely varied character. The urea was decomposed in all and very rapidly in most of the samples.

The rapid conversion of urea to ammonia makes urea nitrogen resistant to leaching. An Iowa soil scientist (16) suggests fall fertilization when the soil temperature is already below 60° F., as bacteria in warm soils convert the material to the nitrate form which rain water leaches out.

Urea moves less readily in soil than nitrate nitrogen but more readily than ammonium nitrogen because urea is held on clay by weak adsorptive forces. Most of the urea is free to move downward into the root zone before becoming fully fixed or immobilized as ammonium. As soils warm in the spring the bacteria become active unlocking the stored ammonium and converting it to nitrate nitrogen.

Most of the nitrogen applied to the soil in the form of urea will be absorbed by plants as ammonium or nitrate ions (18, 54). However, nitrogen can be directly absorbed as urea by roots and foliage, acted upon by the urease enzyme and finally converted to amino acids or proteins. The nitrogen utilized by plants is derived primarily from the inorganic forms and nitrates are in general considered to be the most available of the nitrogenous compounds (5).

The wheat plant (*Triticum* spp.) absorbs much of its nitrogen usually in the nitrate form by the time it blooms, but absorption continues until the crop is nearly ripe. The plant attains a maximum content of nitrogen three weeks before harvest, but the accumulation of protein continues about one week longer (6). Only about 8-22 percent of the total amount of nitrogen in winter wheat plants in Kansas is absorbed from October to March. About 80 percent of the nitrogen is absorbed during the 7-12 week period after March 15 following the resumption of the spring growth. The amount of nitrogen in the stems and leaves reaches its peak at about the time of heading, after which it decreases until harvest time. Nitrogen begins to increase in the heads about the time it starts to decrease in the stems and leaves. The nitrogen content of the grain increases from the beginning of grain formation until maturity (29, 44). Carpenter et al. observed, however, that the uptake of nitrogen by wheat on low-N soils fell off rapidly after the plants reached the heading stage, while uptake continued on the high-N soils (9).

The principal protein in the wheat kernel is gluten, composed of gliadin and glutenin. Non-gluten proteins present include albumin and globulin. The gluten is formed in the developing kernel from translocated amino acids and amides. These simpler nitrogen compounds predominate at the outset of kernel formation but are subsequently changed into the protein of the wheat grain. A high protein content of the grain is favored by a more rapid deposition of protein than starch in the kernel early in the postfloral period.

Phosphorus plays a significant role in the nutrition of the wheat plant. Winter wheat plants in Kansas absorb about 12-25 percent of the total available P by March 1. After this period, absorption is very rapid. It was observed that the bulk of the P in the plant was attained about two weeks before harvest (31, 36).

Potassium also has a significant role in the nutrition of the wheat plant particularly during the active formation of carbohydrates. In Kansas, the K absorbed by March 15 did not exceed 12 percent of the maximum amount. The absorption of K markedly increases as soon as the rapid growth starts in spring, and the plant attains its maximum content of K about 7 weeks before harvest. A substantial loss in K has been observed during the final 6 weeks before ripening of the grain, as this element can be leached from the dried leaves (31, 36).

Nitrogen is beneficial on most soils unless moisture is the limiting factor. However, moisture is normally considered a limiting factor in areas that receive less than 12 inches of precipitation annually (47). Early seeded winter wheat requires relatively small amounts of nitrogen for fall growth. Late fall seedings require even less. These requirements for N may be met by the soil supply or a moderate fertilizer application (44).

Wells _et_ _al_. (58) in a three-year experiment on a clay loam soil reported that nitrogen was successfully applied in fall, spring or as a split application in fall and spring for wheat and oats. Laude and his co-workers (28) stated that in eastern Kansas where the need for nitrogen is more general than that for phosphorus, wheat responded to commercial fertilizers. However, a variable response was recorded in western Kansas because moisture had a greater effect on wheat production than did fertilizers.

Widdowson _et_ _al_. (59) observed that lower wheat yields resulted from a single fall application of N than from a single spring application. These workers also determined that the percent of N in the grain was highest with a May top-dressing of N, lowest with fall applied N, and intermediate with March top-dressings.

Similar findings were reported by Eagle (17). He noted that wheat yields on soils low in N responded best to early spring applications of fertilizer N. Soils with moderate to high N contents gave their best responses with late spring applications. The most severe lodging occurred on plots receiving N in March.

Results of a one-year nitrogen top-dressing study conducted by Long *et al*. (31) indicated that delaying the date of nitrogen application to May 4 resulted in significantly lower yields but resulted in a significantly higher protein content of the grain. The *pearling index*, an inverse measure of kernel hardness or protein content, was significantly lower on wheat receiving N on May 4, which indicated a higher protein content. Higher rates of N fertilization resulted in a higher protein content of the grain especially when the N applications were late.

Earlier findings by Davidson (15) lend support to the results of Long and co-workers. Davidson applied sodium nitrate and calcium nitrate to soft red winter wheat at three dates, April 11, April 24, and May 14. Highest yields were obtained after the earliest date of application. Yields declined as the time of application approached the heading stage. Davidson also determined that the later the application of N, the greater the increase in the protein content of the grain.

Smith (50) reported that N fertilizers, particularly inorganic forms, usually increase the protein content of the grain when applied late in the growing period up to the heading stage or even slightly later. The addition of phosphate fertilizers in liberal amounts often increased the grain yield with a consequent reduction in protein content. Potash fertilizers generally did not affect the protein content of the grain. Smith also reported that management practices such as fallowing or early seedbed preparation which resulted in a build up of soil nitrates, increased the protein content of the grain in addition to increasing yields. Experiments at Oklahoma (38) have resulted in similar conclusions.

Workers in Indiana (55) have indicated that fall applications of N fertilizers had little effect on kernel hardness. Application of phosphates or mixed fertilizers that contained phosphates increased the yield but decreased the vitreousness and protein content of the grain as well as the loaf volume of the bread. The unfertilized plots produced wheat of low yield and shrunken grains but relatively high in protein content.

Work carried out in Illinois (37) has demonstrated that wheat is especially sensitive to a shortage of phosphate during the early stages of growth. Mixed fertilizers topdressed in the spring were less effective than when drilled at seeding time.

Arkansas investigations (58) indicated that fall application of high rates of N may cause winter kill. Delaying application beyond April 15 resulted in depressed yields and sometimes green heads in the grain at harvest time. Almeida et al. (1) found that N top-dressed at heading on various soils produced lower yields than top-dressing at tillering or at tillering and shooting.

Research conducted at the University of Tennessee (57) did not detect significant differences in yields of wheat arising from fall and spring top-dressings of urea. Long and Ewing (32), however, had earlier reported that N applied in the spring was more effective than fall application at seeding time, thus agreeing with the work of Wells and Keogh (58). Further contradiction is added by the work of Littler (30) who observed a greater yield response with urea applied at seeding time when the soil moisture was adequate.

Considerable interest has been expressed relative to the possible injurious effects of nitrogen applied with the seed. Smith (50) reported that experiments in Kansas on heavy soils under ideal moisture conditions showed no damage to wheat germination when as much as 300 pounds per acre of ammonium nitrate in combination with some phosphate and potash, was applied in the drill row directly in contact with the seed. On the other hand, damage was negligible when as much as 40 pounds per acre of N as a component of mixed fertilizer was placed by the same method, in this case under droughty conditions. Some delay in germination was caused by the extra nitrogen but the ultimate stand of wheat plants was about the same as for the nonfertilized plants. Phosphates also can be applied in direct contact with the seed at the time it is drilled. Under droughty conditions, no damage occurred when 200 or more pounds of 0-46-0 fertilizer were used in this manner. However, potash caused injury to germination even in moderate amounts, especially when combined with some amount of N.

The amount of protein in the grain is believed to be regulated by the availability of the supply of nutrients to the wheat plant. Several studies (2, 3, 53, 56) have shown that increasing the N in the soil had a positive effect in increasing the protein content of the grain.

Applications of urea and urine can increase the protein content of wheat by as much as 4 percent (56). By means of foliar applications of urea during the fruiting period, Finney _et al_. (20) obtained an increase of 8.8 percent protein in wheat grain. A number of sprayings throughout the fruiting stage increased protein from 10.8 to 21.0 percent. Similar results were reported by Seth _et al_. (49) using wheat of low and high protein varieties. Phosphorus applications, on the other hand, have been shown to significantly decrease the protein content of the grain (2, 38, 50, 55). These effects merit particular attention since the grain protein content is considered to be one of the most important qualitative characteristics of the wheat crop.

McNeal _et al_. (33) performed experiments probing the protein content of the different kernels in a spikelet. They found that the lateral kernels contained more protein than did the central kernels, while grains from the middle of the spike were higher in protein content than those from the top of the spike. These differences indicate that the earlier formed and matured kernels contain the highest protein. This suggests the need for high N availability late in the growth period for maximum protein content.

Neidig and Snyder (40, 41) have given these rules of thumb concerning the yield and protein content of wheat as affected by moisture and available N: (a) a high moisture content in the soil containing sufficient available N for the maximum growth and development of wheat plant results in high yielding wheat containing a high percentage of protein, (b) a low moisture content in soil containing an excess of available N results in a lower yield of wheat but a higher protein content, and (c) a high or optimum moisture content in soil which has a considerable amount of N available for the wheat in the early periods of growth but an insufficient amount during the fruiting and ripening periods results in a high yield of wheat of low protein content.

Another qualitative characteristic of wheat grain is yellow berry. This is a condition which is believed to be due to nitrogen deficiency causing a high ratio of carbohydrates to protein in the grain (35). It is characterized in hard wheats by the light colored appearance of an appreciable portion of the kernel which is soft in whole or in part. If the berry is soft only in spots, it has a mottled appearance, the lighter portion being soft and chalky and the darker portion harder (21, 48). The yellow berry kernels have been found to be higher in moisture and starch contents and lower in protein and ash than the hard and flinty ones. Yellow berry is also believed to be associated with late dates of ripening (45).

In Kansas, Heyne _et al_. (24) have pointed out that yellow berry wheat is due mainly to a wet season or lack of nitrogen. In the western part of the state, wheat is usually grown under less humid conditions and often with higher available N in the soil than in eastern Kansas. The incidence of yellow berry has been highly correlated with lack of protein in wheat. The same authors observed that when N increased protein content, the sedimentation value rose proportionately. Smith _et al_. (51) have reported that yellow berry was quite apparent in grains produced on unfertilized plots at N-responsive locations. Reitz and Meyers (43), on the other hand, noted that applications of phosphate fertilizer substantially increased the percentage of yellow berry grains.

Another indicator of the quality of wheat is test weight. Grain that is not filled completely will have a low weight per bushel. A low test weight is likely to be associated with a high protein content and vice versa. Results obtained by Reitz _et al_. (43) relative to the use of phosphate fertilizer have confirmed this. This phenomenon is explainable by the fact that protein is deposited in the grain earlier than the carbohydrates. If the filling of the grain is cut short by hot winds, dry weather or other unfavorable climatic factors, the grain is left relatively high in protein. However, test weight cannot be regarded as a reliable index of wheat protein content (8).

Other conditions which may lead to low test weight include excessive moisture, pathological conditions such as rust and scab, and both insufficient and excessive amounts of available nitrogen. Smith and co-workers (51) found that at locations unresponsive to fertilizer nitrogen, test weight values tended to decline even with applications of only 25 pounds of N per acre. Further reductions in test weight occurred with increased nitrogen applications.

This review of the literature pertinent to the nitrogen fertilization of wheat has demonstrated that several gaps exist in the available information, particularly in regard to the value of urea as a solid N fertilizer and to the most desirable time of N application. The object of this study is to attempt to supply some of the missing information.

MATERIALS AND METHODS

Fertilizer Materials: The nitrogenous fertilizer materials used in this study, prilled ammonium nitrate and urea, were provided by the Davison Chemical Division of W. R. Grace and Company. Phosphorus was supplied as triple superphosphate (0-46-0) and potassium, where needed, as potassium chloride (0-0-60).

Experimental Sites: The study was conducted for two years (1964, 1965) at five locations on soils of varied character. The sites and the soil types involved were: Ashland Agronomy Farm, Sarpy fine sandy loam (1964); Manhattan Agronomy Farm, Geary silty clay loam (1965); Newton Experiment Field, Goessel silty clay loam; Columbus Experiment Field, Parsons silt loam; Sandyland Experiment Field, St. John, Carwile fine sandy loam; and Richard Evans Farm, Hutchinson, Pratt fine sandy loam.

Composite soil samples were collected at each of the experimental sites. These samples were analyzed for organic matter, available phosphorus (determined by Bray's sulfonic acid reduction method with 0.03 N NH_4F and 0.025 N HCl as extracting solutions), exchangeable potassium, and soil acidity by the Kansas State Soil Testing Laboratory. Results of the soil analyses are presented in Table 1.

Experimental Design: Twenty fertilizer treatments were included in the study. These treatments are detailed in Table 2. A randomized complete block design was employed

Table 1. Soil test data for the two-year urea fertilizer study.

Location	pH	Lime Reqmt. Lbs./A.	Avail. P Lbs./A.	Exch. K Lbs./A.	Org. Mat. %
			1964		
R. Evans Farm, Hutchinson	5.2	Min. 6,000 Max. 7,000	70	500+	2.0
St. John Exp. Field	5.7	Min. 3,000 Max. 4,000	63	464	0.8
Ashland Agron. Farm	7.2	Min. ----- Max. -----	110	500+	1.5
Newton Exp. Field	6.0	Min. 4,000 Max. 5,000	18	500+	2.0
Columbus Exp. Field	6.1	Min. 3,000 Max. 4,000	19	343	1.6
			1965		
R. Evans Farm, Hutchinson	5.5	Min. 5,000 Max. 6,000	25	500+	1.7
St. John Exp. Field	6.9	Min. ----- Max. -----	71	349	0.8
Manhattan Agron. Farm	6.0	Min. 4,000 Max. 5,000	15	500+	1.9
Newton Exp. Field	6.1	Min. 3,000 Max. 4,000	21	500+	1.9
Columbus Exp. Field	6.3	Min. ----- Max. -----	10	96	1.5

Table 2. Fertilizer treatments.

Treatment	Amount of fertilizer applied per plot
1. Check	0
2. Phosphate only	10.5 ozs.
3. N-25 drilled before seeding - urea	11.0 ozs.
4. N-50 "	1 lb., 5.5 ozs.
5. N-100 "	2 lbs.,11.0 ozs.
6. N-25 drilled before seeding - NH_4NO_3	14.5 ozs.
7. N-50 "	1 lb., 12.5 ozs.
8. N-100 "	3 lbs., 9.5 ozs.
9. N-25 top-dressed - urea	same as treat. 3
10. N-50 "	" 4
11. N-100 "	" 5
12. N-25 "	" 3
13. N-50 "	" 4
14. N-100 "	" 5
15. N-25 "	" 3
16. N-50 "	" 4
17. N-100 "	" 5
18. N-25 "	" 3
19. N-50 "	" 4
20. N-100 "	" 5

with four replications per treatment. Each plot was 100 feet long and 63 inches wide (nine drill rows). Drilling and seeding operations were accomplished by means of a grain-drill with a fertilizer attachment.

A blanket treatment of triple superphosphate (55 pounds of P_2O_5 per acre) was applied to the entire experimental area at each site with the exception of the check plots. At the Columbus Experiment Field, 21 pounds per acre of KCl were applied to all but the check plots to overcome the low potassium status of the soil (Table 1). The potassium treatment at Columbus was applied with a grain drill with the phosphorus. In all instances, phosphorus was banded with the seed. Drilled applications of ammonium nitrate and urea were applied to the plot areas prior to seeding in order to avoid possible injury to the germinating seed by the hydrolysis of urea. In 1965, however, the usual procedure for drilled applications of nitrogen was not followed at the Manhattan Agronomy Farm. In this instance, both nitrogen carriers were banded with the seed.

Seeding rates were varied from 4 to 6 pecks at the individual sites due to variation in the mean precipitation. Four pecks were seeded at Sandyland, six pecks at the other sites. Varieties of wheat sown included Triumph on the Evans and Newton sites, Concho at Sandyland, and Ottawa at Ashland, Manhattan, and Columbus. The several varieties were utilized to coincide with the type of certified seed produced on the experimental fields.

Urea top-dressings were carried out manually. Pre-weighed aliquots of the material were spread over the entire plot area. The dates of nitrogen top-dressing for the various sites in 1964 and 1965 were:

1964 Locations

Treatment	Hutch.	Newton	St. John	Ashland	Columbus
9, 10, 11	Feb. 20	Feb. 20	Feb. 20	Feb. 27	Jan. 15
12, 13, 14	March 5	March 5	March 5	March 12	Feb. 12
15, 16, 17	" 24	" 24	" 24	" 30	March 1
18, 19, 20	Apr. 8	Apr. 8	Apr. 8	Apr. 15	" 15

1965 Locations

Treatment	Hutch.	Newton	St. John	Manhattan	Columbus
9, 10, 11	Feb. 19	Feb. 19	Feb. 19	Feb. 19	Jan. 15
12, 13, 14	March 12	March 12	March 12	March 12	Feb. 15
15, 16, 17	Apr. 12	Apr. 12	Apr. 12	Apr. 12	March 1
18, 19, 20	May 5	May 5	May 5	May 5	" 15

The plots were harvested by means of a combine. The grain from each plot was weighed in the field to determine yield and a two-pound aliquot retained for chemical and qualitative analyses.

Chemical and Qualitative Analyses: The grain samples were cleaned by the use of a Carter Dockage Tester sieve cleaner. Samples in paper sacks were then allowed to air dry until constant weights were obtained. Determination of test weights followed using an Ohaus Seedburo scale. These were expressed in pounds per bushel. Aliquots of the clean grain were then placed in small air-tight bottles for further analysis.

Techniques for the determination of yellow berry were acquired from Professor Howard Wilkins of the Department of Agronomy, Kansas State University. Two hundred grains were collected at random from each sample. Two people were employed for this job in order to provide a check on counting and examination. The grain was examined by means of a magnifying glass when kernel color was generally light.

Plumpness of the grain was determined by weighing 100 kernels selected at random from each sample. This test was included due to the author's belief that high test weights might not always be correlated with plumpness.

Aliquots of the grain saved for protein analysis were finely ground through a Labconco modified burr-type mill. The determination of nitrogen in the grain followed the procedure described by Jackson (26) but with the following modifications. A mixture of K_2SO_4, $FeSO_4$, and $CuSO_4$ ($10:1:\frac{1}{2}$) was used as the digestion accelerator. Prepared methyl purple with a pH range of 4.8 to 5.4 was used as the indicator in the titration process. Exactly 1 g of oven-dried ground grain was placed in an 800 ml Kjeldahl flask along with the digestion catalyst and 30 ml of concentrated H_2SO_4. The mixture was digested until the solution attained a light yellow-green color. To the cool digest, about 100 ml of cool water was added plus 110 ml of 40 percent NaOH solution.

The distillates were collected in 4 percent boric acid solution and back-titrated with 0.0714 N H_2SO_4. A factor of 5.7 was used for protein conversion.

Efficiency on the recovery of N by the Kjeldahl apparatus was determined by using an $(NH_4)_2SO_4$ solution known to have 1 mg N per ml. The mean percent recovery was found to be 99.

Statistical Analysis: Analysis of variance of the yield, protein content, test weight, yellow berry, and plumpness data was carried out via the methods described by Snedecor (52) and Federer (19). Snedecor's F values at the 5 percent level were selected as the basis for determining the significance of the F-tests of the treatment mean squares. Fisher's least significant differences based on t-values at the 5 percent level were used to test treatment means.

RESULTS AND DISCUSSION

Detailed data from this study are presented in the Appendix.

R. Evans Farm, Hutchinson: In 1964, significant increases in grain yields were obtained with the addition of nitrogen. Drilled applications of nitrogen applied before seeding appeared to produce higher yields than the rest of the treatments, especially the two highest rates of application of N. April applications of urea nitrogen produced the minimum yield increases. This is shown especially by the N-25 rate of spring-applied urea which proved inferior to a similar drilled treatment of ammonium nitrate and the March 5 applications of urea at the same rate. The result may be attributed to the fact that utilization of nitrogen is rapid during the early growing season. A comparison of the lowest yield, 40.81 bushels obtained from the N-25, April application, and the yield of the plots with no fertilizer at all, 35.29 bushels, points out the need for a fertility program for this location. Statistical analyses showed that the P-only treatment was as effective as treatments 3 and 6, which were drilled before seeding.

In most treatments, the date and rate of N top-dressing application did not appear to have a significant effect on the yield. The 25 pound rate of N seemed to be adequate for wheat production if only yield was considered.

In 1965, there was also a marked increase in yield after the addition of nitrogen. In most cases, there were significant increases in yield as the N rate was increased, except in the case of the May 5 application. This can be explained by the fact that the latest top-dressing was applied when the wheat was in the boot stage which caused a delaying effect on the maturity of the grain. In the case of the latest spring applications, the yields decreased as the rate of N increased; among the plots receiving spring treatments with the same amount of N, yields were depressed as the date of N application was postponed (Fig. 1). Generally, the drilled applications, during the two years, of both sources of N, especially at the N-50 and N-100 rates, tended to produce the highest yields. The effects of the drilled N carriers are shown in Fig. 2. Again the difference in yield between the check plots (29.8 bushels) and that from the N fertilized plots (38.1 bushels) proved the necessity for a sound fertility program.

Application of P also produced a marked increase in yield. The effects of P fertilization are presented in Table 3.

Generally speaking, both years' data revealed that application of the entire amount of N in the fall before seeding was superior to the application of all the nitrogen in the spring as a top-dressing.

In both 1964 and 1965, the protein content of the grain increased as amount of N applied increased (Fig. 3). In all

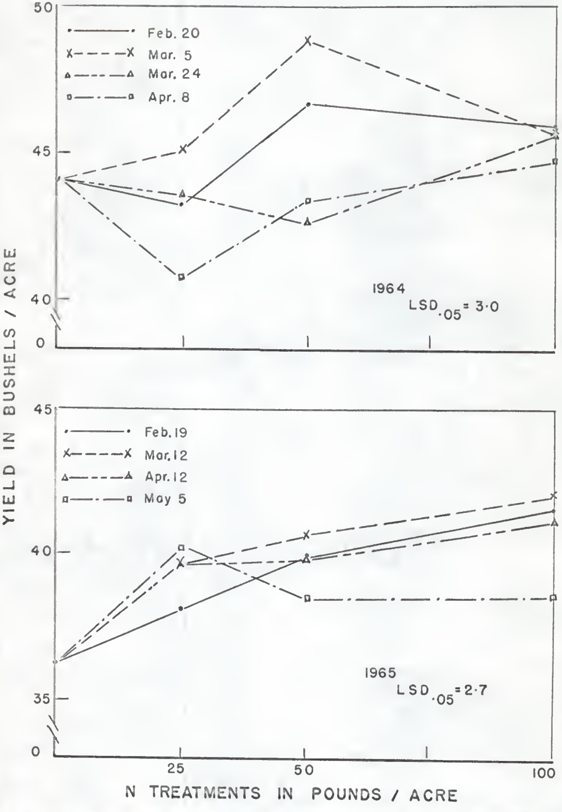

Fig. 1. The effects of urea-N top-dressed at 4 different dates on the yield of hard red winter wheat, Richard Evans Farm, Hutchinson.

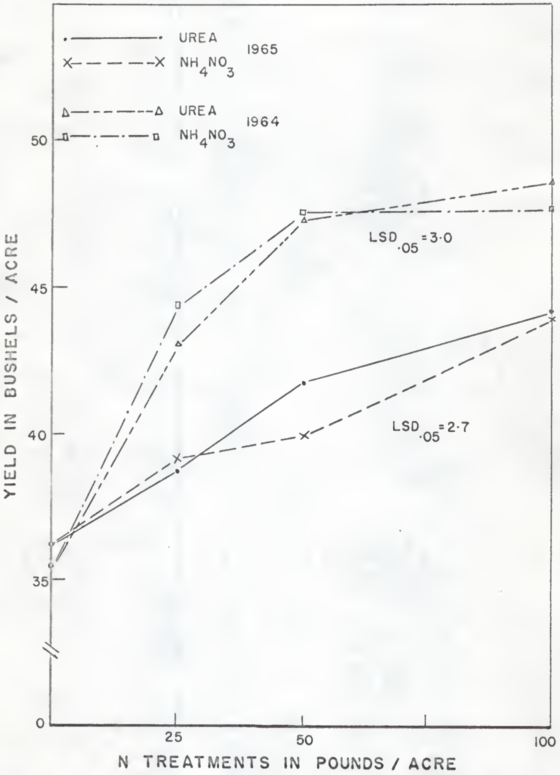

Fig. 2. The effects of drilled N treatments employing 2 N carriers on the yield of hard red winter wheat, Richard Evans Farm, Hutchinson.

Table 3. Effects of P fertilization.

	Treatment		Yield Bu./A.	% Protein	Test Wt. Lbs./Bu.	Yel. berry %	Wt. 100 grains, g
1.*	0-N	1964	35.3	11.2	60.0	-	-
	P only		44.1	11.2	60.1	-	-
	0-N	1965	29.6	11.0	61.1	5.8	3.127
	P only		36.2	10.2	61.8	17.2	3.278
2.	0-N	1964	30.9	11.8	61.3	7.2	-
	P only		35.4	11.7	61.3	11.2	-
	0-N	1965	29.8	10.1	60.4	6.5	2.911
	P only		23.1	10.2	59.4	6.5	2.780
3.	0-N	1964	47.4	10.2	58.2	-	-
	P only		41.8	10.4	58.0	-	-
	0-N	1965	31.8	13.3	59.8	8.0	2.384
	P only		37.2	12.0	59.6	12.0	2.459
4.	0-N	1964	30.5	10.2	60.5	12.6	-
	P only		35.0	9.9	59.8	8.3	-
	0-N	1965	-	11.6	59.1	8.2	2.992
	P only		-	11.9	59.9	9.0	3.150
5.	0-N	1964	33.3	12.1	59.1	5.8	-
	P-K only		40.7	12.4	58.8	3.5	-
	0-N	1965	41.6	11.2	58.8	-	2.254
	P-K only		54.9	10.4	59.4	-	2.354

* 1. R. Evans Farm, Hutchinson
2. Sandyland Exp. Field
3. Ashland and Manhattan
4. Newton
5. Columbus

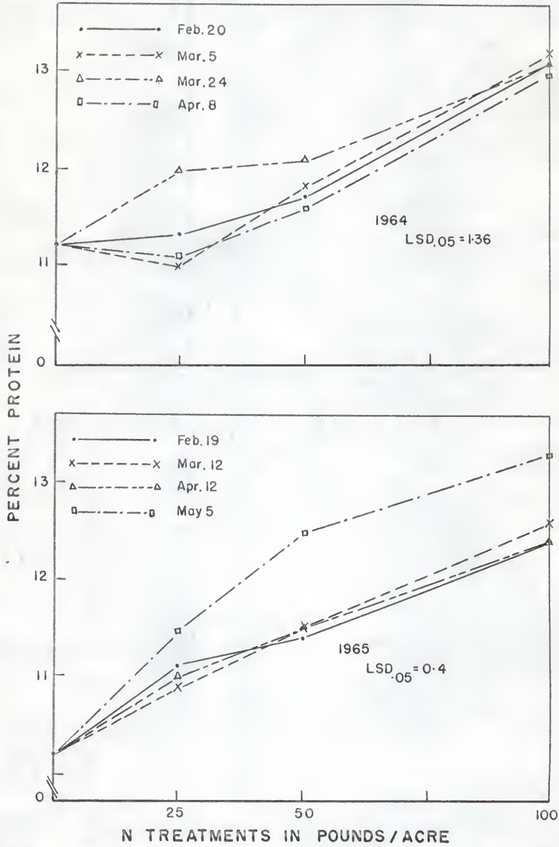

Fig. 3. The effects of urea-N top-dressed at 4 different dates on the protein content of hard red winter wheat, Richard Evans Farm, Hutchinson.

instances, the N-100 rates resulted in the highest protein contents, then the N-50 and N-25, in decreasing order. The effect of date of N application on the protein content of the grain varied between the two years' data. In 1964, the highest protein contents were obtained from drilled applications of NH_4NO_3 (13.21 and 14.18 percent for the N-50 and N-100 rates respectively) while the highest protein contents in 1965 were obtained from the latest spring application (12.5 and 13.3 percent). The application of P tended to decrease the protein content as is specifically indicated by the 1965 test (Fig. 4). Generally speaking, the protein content of the 1965 crop was lower than that of the 1964 crop. This can be explained by the fact that there was more total precipitation during the 1965 growing season (Appendix Tables 12 and 13). Also, the relatively lower average temperature which prevailed during the 1965 growing season (Appendix Table 15) might be a major factor in inducing this phenomenon.

In 1964, the treatments did not have a significant effect on test weight. This was not the case in 1965. It is shown by the 1965 data that the N-25 rates applied in the spring produced the highest test weights. In both years, it was clearly evident that the highest amounts of N generally produced the lowest test weights. It is a well-accepted concept, however, that a lower test weight is likely to be associated with a high protein content and vice versa. This is usually explained by the assumption that the protein is

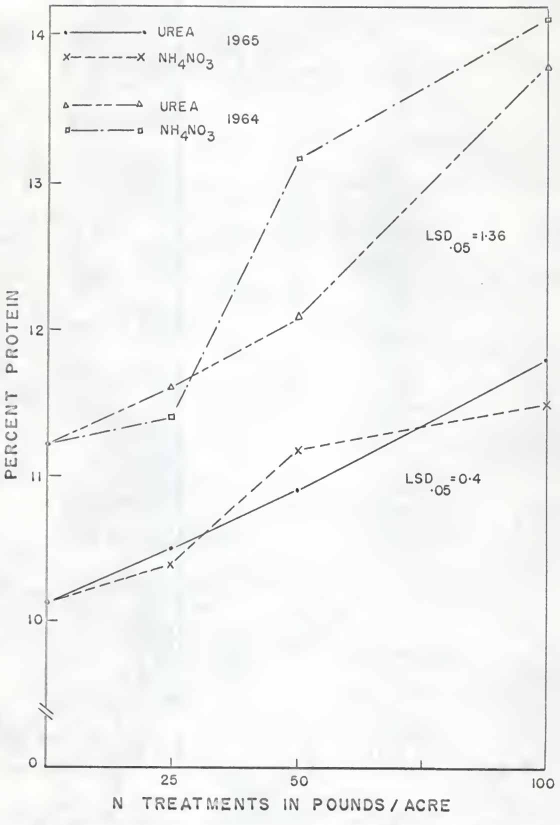

Fig. 4. The effects of drilled N treatments employing 2 N carriers on the protein content of hard red winter wheat, R. Evans Farm, Hutchinson.

deposited in the grain earlier than the carbohydrates and if the filling of the grain is cut short by hot winds, dry weather or other climatic factors, the grain is left relatively high in protein content. Grain that is not filled completely will be low in test weight while grains well-filled are high in test weight. Consequently, low test weight is associated with the high protein content of prematurely ripened wheat and high test weight with the lower protein content of plump, completely filled grain. But the test weight cannot always be regarded as a reliable index of wheat protein content. The average test weight of the 1965 crop was higher than that of the 1964 crop.

The qualitative analyses made in 1965 included the plumpness test (by weighing 100 kernels from each plot) and percent yellow berry. The 1964 grains were too bleached to allow a reliable yellow berry determination.

In the 1965 data, test weights and plumpness are similar in many respects. There was a general tendency for the highest rates of N to produce grain with the lowest test weights and plumpness with the lower N rates producing grain with the highest values. Plots which did not receive any fertilizer gave grain with the lowest test weight and plumpness of all treatments.

In regard to the yellow berry test, grains from the low N plots were significantly higher in yellow berry content when compared with those from plots receiving 100 pounds of N. In no instance was the percent yellow berry higher after the high N treatments. Apparently, the differences in dates, sources and methods of application among treatments of equivalent amounts of N did not have a significant effect on the yellow berry content of the grain.

Sandyland Experiment Field, St. John: In 1964, yields were not significantly affected by the rates, sources, methods, and dates of N application. The plots receiving no fertilizer at all produced the lowest yield. The P-only application tended to increase the yield.

In 1965, there was a marked increase in yield at the two highest rates of N including the drilled-before-seeding applications and the first spring application. From the standpoint of statistical importance, there was no significant response to the 25-pound N rate regardless of the carrier or the time of application. A significant response to the 50-N rate was observed only at the first spring top-dressing date. Again, the latest spring top-dressing proved to be of no significance as far as the yield was concerned. Yields obtained from all rates on this date were even lower than from the check plots. This can also be explained by the fact that the top-dressing was carried out when the wheat was about to reach the boot stage; the maturity of the grain thus being adversely affected (Fig. 5). In the case of the drilled applications in 1965, the NH_4NO_3 produced significantly higher yields than did urea, particularly at the higher rates of N application (Fig. 6). The average 1965 yield was lower than that of the 1964 crop. This may be due

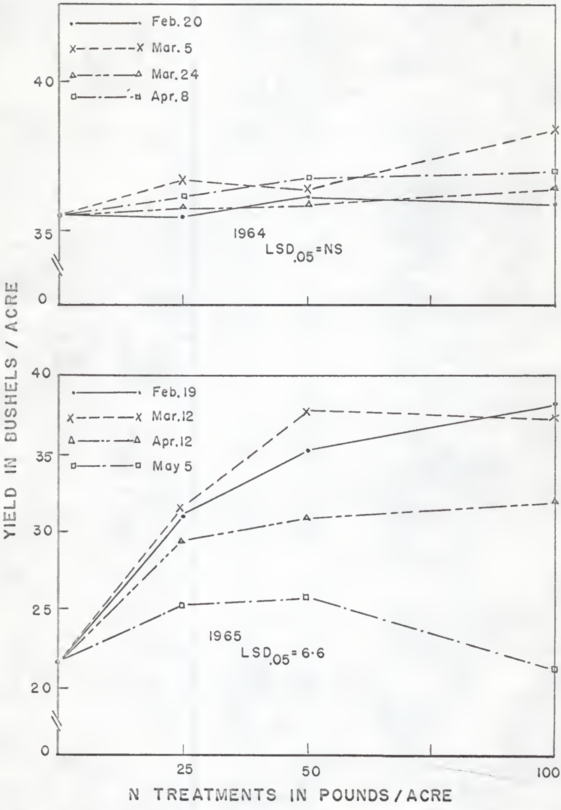

Fig. 5. The effects of urea-N top-dressed at 4 different dates on the yield of hard red winter wheat, Sandyland Experiment Field, St. John.

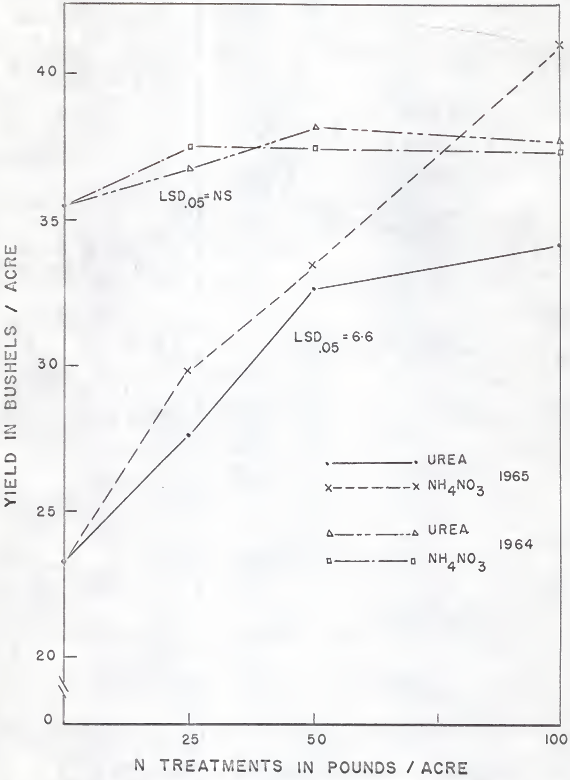

Fig. 6. The effects of drilled N treatments employing 2 N carriers on the yield of hard red winter wheat, Sandyland Experiment Field, St. John.

to the relatively lower temperature which prevailed during the growing season of 1965. There was no response to the P-only treatment in 1965.

There were significant effects of N application on the protein contents of the grain in both 1964 and 1965. At no date, source, method, and rate of N application was the protein content inversely related to the N treatment. An apparent increase of the protein content was obtained from the spring top-dressings in 1965. The greatest increase in protein was produced by the latest (May 5) application of urea-nitrogen (Fig. 7). This is in contrast to the 1964 results, where the highest level of protein resulted from the ammonium nitrate drilled before seeding (Fig. 8). Again it is evident that there is an excellent relationship between the protein content of the grain and the rate of application of N. However, a marked decrease in protein was noted as a result of the treatment involving only phosphate. The average protein content of the 1965 crop was lower than of the 1964 crop which can be attributed to the higher total precipitation and lower average temperature which occurred during the wheat growing season (Appendix Tables 12, 13, and 15).

The 1965 test weight results were quite different from those of 1964 (Appendix Tables 3 and 4). In 1964, differences in test weights were not significant but there was a tendency for test weights to decline with increasing N treatments. Test weight differences were significant at the .05

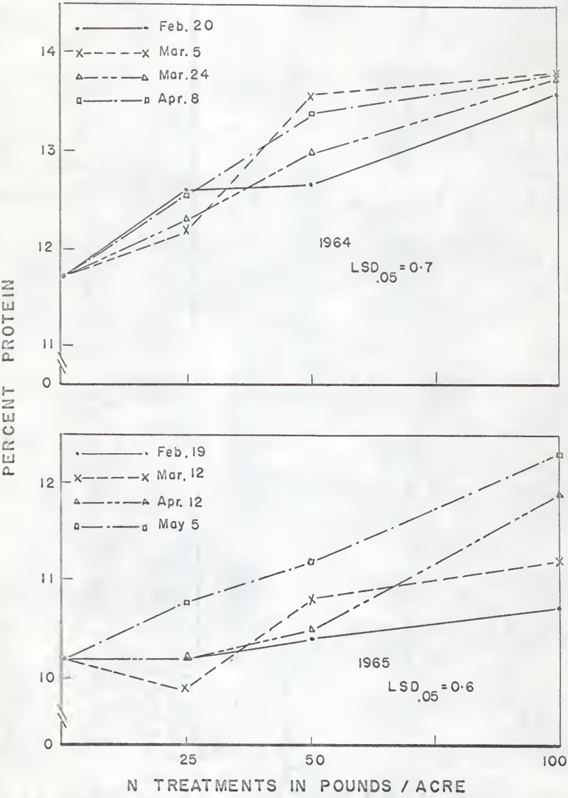

Fig. 7. The effects of urea-N top-dressed at 4 different dates on the protein content of hard red winter wheat, Sandyland Experiment Field, St. John.

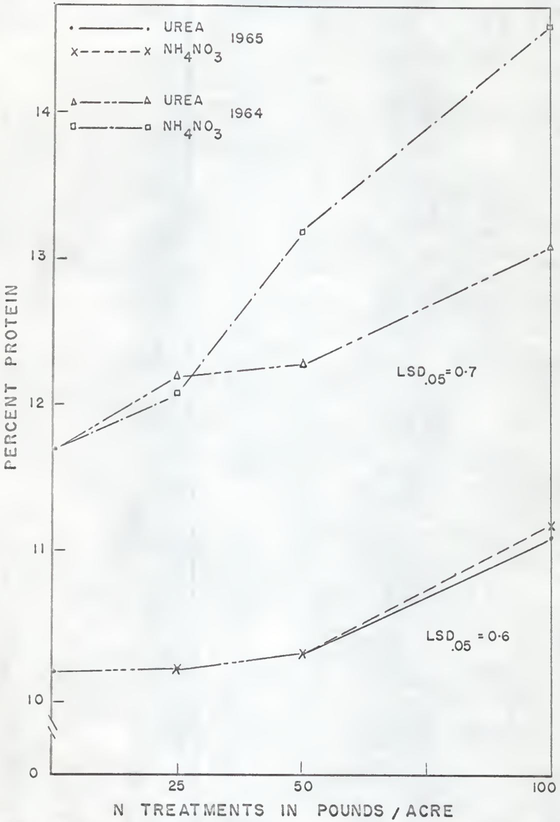

Fig. 8. The effects of drilled N treatments employing 2 N carriers on the protein content of hard red winter wheat, Sandyland Experiment Field, St. John.

level in 1965 but not at all dates of application. The phosphate application did not have a significant effect on the test weight in either 1964 or 1965. Generally, test weights of the 1965 crop were lower than those of 1964.

Plumpness of the grain (weight per 100 grains) was directly related to the test weight in 1965. The lowest weight per 100 kernels corresponded to the lowest test weight but had the highest protein content. Both were significantly affected by the N application.

Both years' data showed the percent yellow berry to be affected by the application of nitrogen and phosphorus. Among the sources of variation, the rates of N gave the most significant effect. For instance, most of the 1965 N-25 and N-100 treatments produced significant differences. This was not true, however, for 1964. The P-only treatment tended to give the highest percent yellow berry. Among the N treatments, N-25 rates gave the highest average percent yellow berry and the N-100 the lowest.

<u>Ashland and Manhattan Agronomy Farm</u>:* In both 1964 and 1965, grain yields were not significantly affected by the N and P applications (Appendix Tables 5 and 6). However, there was a slight modification of treatments for 1965 at the Manhattan Agronomy Farm. The nitrogen fertilizers were drilled with the seed and only treatment 2 received phosphate. It was observed that plants on most plots receiving high rates

*Due to damage of winter-kill and weeds, only 2 replications were harvested in 1965.

of N (specifically N-100) showed low or practically no emergence. This is explainable by the theory that higher amounts of N fertilizer withdraw more moisture from the surrounding area, thus depriving the seed of moisture necessary for germination. In the case when urea was drilled with the seed, germination may have been inhibited by the high pH brought on by hydrolysis of the urea.

In 1964, the unfertilized plots at Ashland produced excellent yields which were not significantly different from those obtained after N and P fertilization. In treatments where N sources were drilled before seeding, the 25 pound rate appeared to be better than the other two rates (Fig. 10). Top-dressing applications of 50 pounds of N produced higher average yields than the 25 pound and 100 pound rates (Fig. 9). Lack of response at Ashland may have been due to the extremely dry weather which prevailed during the spring of 1964 (Appendix Table 5). In 1965, plots receiving the phosphorus produced the highest yields. This response may be due to the low available phosphorus content of the soil (Table 1). The N-25 treatment produced the lowest average yield. Lack of response at Manhattan might have been due to the lack of available phosphorus.

Generally, the protein content in 1964 and 1965 increased with increasing rates of N. However, the 1965 results were not significantly affected by N applications even though it was apparent that wide differences existed between the protein content of the grain from the N-25 and/or N-50 and

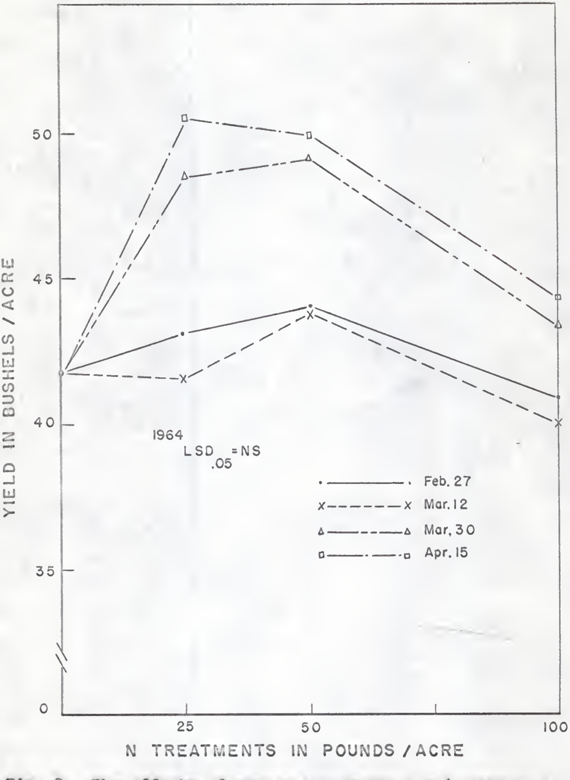

Fig. 9. The effects of urea-N top-dressed at 4 different dates on the yield of hard red winter wheat, Ashland Agronomy Farm.

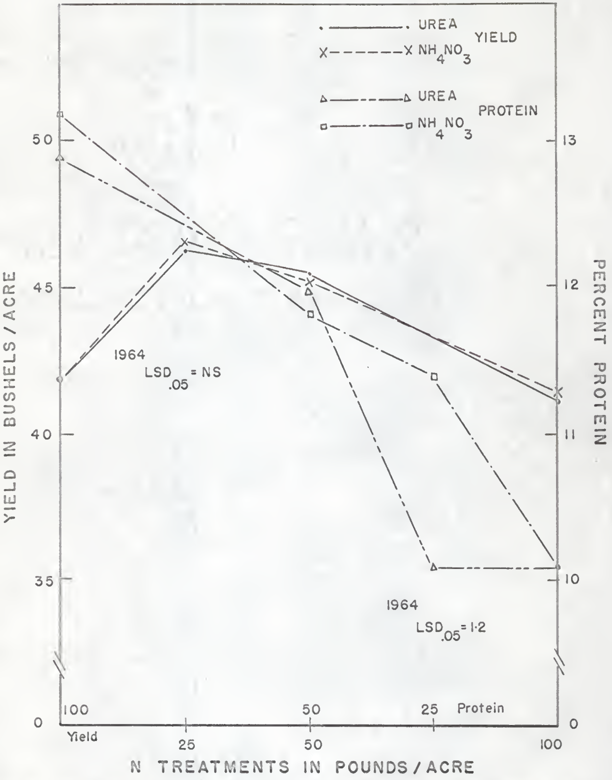

Fig. 10. The effects of drilled N treatments employing 2 N carriers on the yield and protein content of hard red winter wheat, Ashland Agronomy Farm.

N-100 plots. The 1964 data revealed significant effects of N applications on the protein content of the grain (Fig. 11). In all instances, the N-100 treatments were superior in producing high protein grains. The single P treatment produced a significant depression in the protein content of the grain in 1965. Significant differences did not seem to result from variations in dates, sources, and methods of nitrogen application.

Few significant differences were observed in the test weight data in either 1964 or 1965. The plumpness test was without significance. Yellow berry counts were not attempted in 1964 due to the bleached condition of the grain. Yellow berry in 1965 was inversely related to the rate of N fertilization.

Newton Experiment Field: Wheat at Newton responded significantly to N applications in terms of yield in 1964 (Fig. 12 and Fig. 13). In most cases, yields were directly related to the rate of N fertilization. Phosphorus also produced a significant increase in yield in 1964. No yield data were collected in 1965 due to severe winter-kill and severe hail damage in early June. Grain samples were collected, however, for qualitative determinations.

Protein contents were significantly affected by N treatments in both years. There was an excellent positive relationship between protein and N treatment in both years. This was true for both sources of N, drilled and top-dressed (Fig. 14 and Fig. 15). In 1965, spring applications of urea

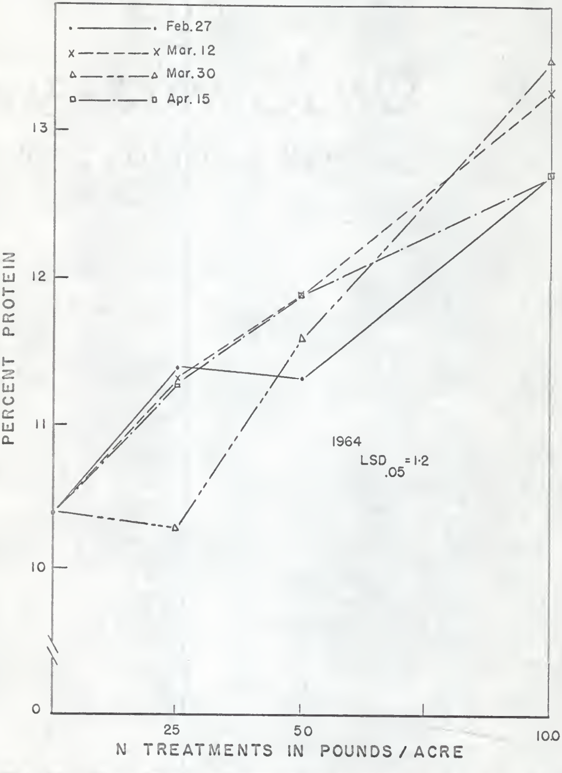

Fig. 11. The effects of urea-N top-dressed at 4 different dates on the protein content of hard red winter wheat, Ashland Agronomy Farm.

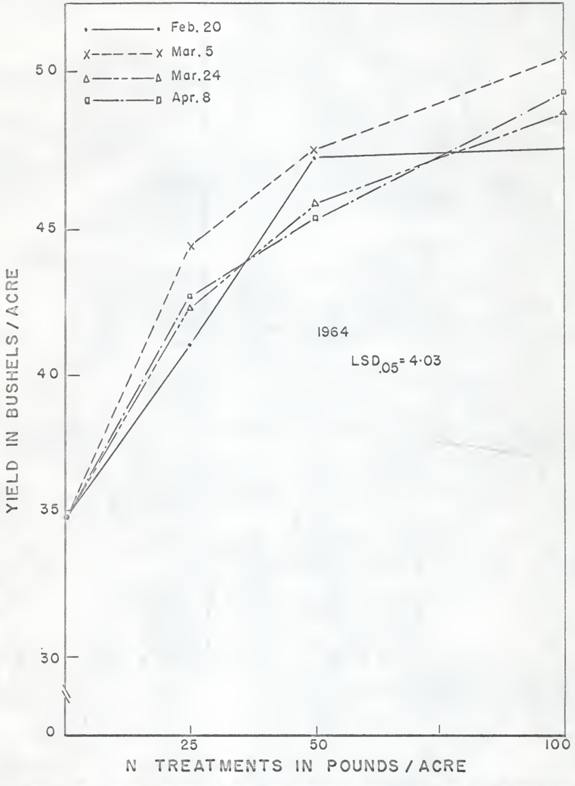

Fig. 12. The effects of urea-N top-dressed at 4 different dates on the yield of hard red winter wheat, Newton Experiment Field.

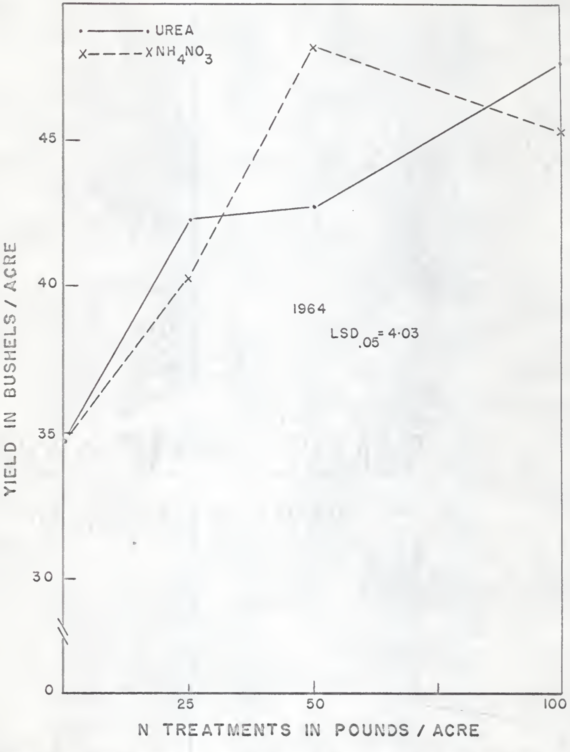

Fig. 13. The effects of drilled N treatments employing 2 N carriers on the yield of hard red winter wheat, Newton Experiment Field.

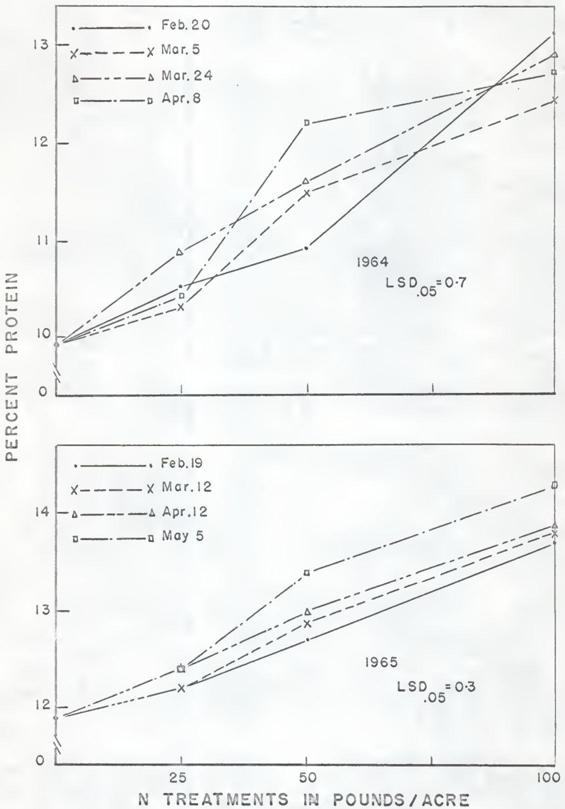

Fig. 14. The effects of urea-N top-dressed at 4 different dates on the protein content of hard red winter wheat, Newton Experiment Field.

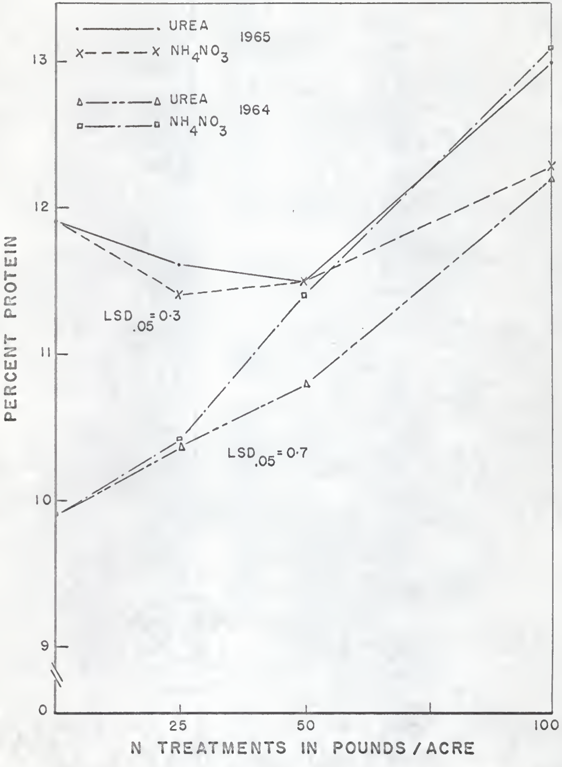

Fig. 15. The effects of drilled N treatments employing 2 N carriers on the protein content of hard red winter wheat, Newton Experiment Field.

were especially effective in increasing the protein content of the grain. Phosphorus significantly depressed the protein content of the grain in 1964. Significant differences existed in the test weights among the data for both 1964 and 1965. The effects of N fertilization on the test weight of the grain, however, were varied and did not follow a particular pattern. A tendency for the test weights to be lower for grain from the plots receiving the late spring N top-dressings was observed in 1965.

Yellow berry determinations followed their usual pattern in both crop years. In all instances, the yellow berry content declined with increasing N applications. Also, there seemed to be an excellent direct relationship between test weight and plumpness (Appendix Table 8).

Columbus Experiment Field: Significant differences in yields were apparent in both the 1964 and 1965 data for the Columbus field. The use of N produced highly significant increase in the yield of grain over that from check plot, but there were few significant differences in yield that could be attributed to different rates of N fertilization. The addition of P and K to the soil also produced sizeable yield increases in both 1964 and 1965. Few significant differences existed in 1965 between plots that had received P plus K as compared to those that received N, P, and K (Appendix Table 10). No significant differences existed between the P-K and N-P-K plots in 1964. Yields in 1965 on this series of plots were among the highest ever recorded at the Columbus field

(Fig. 16 and Fig. 17).

Protein content of the grain was directly related to N fertilization in both crop years. Significant differences were numerous in both years. A direct relationship of protein to N fertilization rates was observed for all dates, sources, and methods of N application (Fig. 18 and Fig. 19). Phosphorus and potassium depressed the protein content of the grain in 1965 but did not significantly affect it in 1964. The 1965 crop was generally lower in protein content than was the 1964 crop.

Considerable variation in the test weight of grain was observed in 1965 but there was a general trend for test weight to decline as the rate of N fertilization increased. Little variation was observed in the 1964 test weights, which were generally below those of 1965.

Rates of N fertilization did not produce significant differences in the results of the plumpness test.

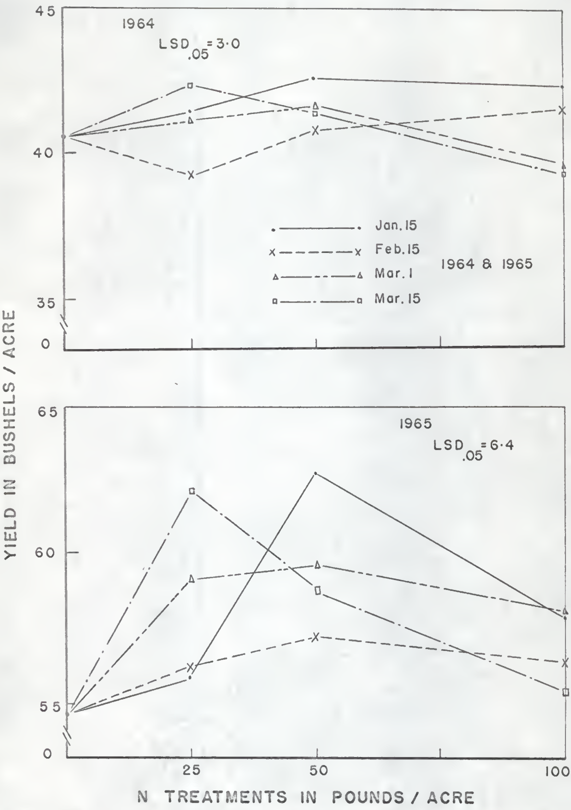

Fig. 16. The effects of urea-N top-dressed at 4 different dates on the yield of hard red winter wheat, Columbus Experiment Field.

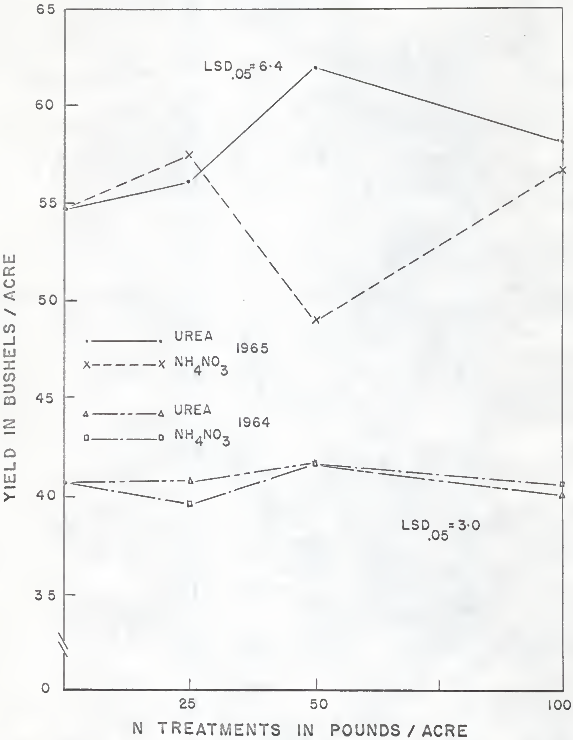

Fig. 17. The effects of drilled N treatments employing 2 N carriers on the yield of hard red winter wheat, Columbus Experiment Field.

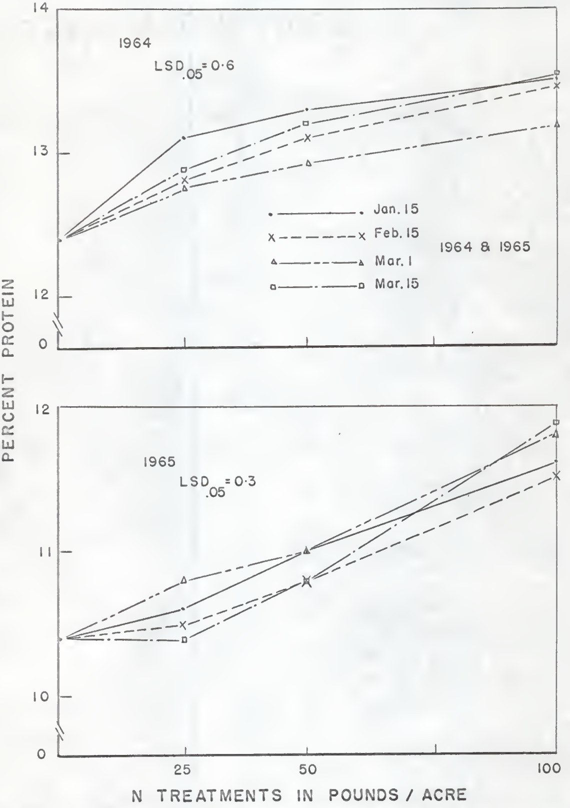

Fig. 18. The effects of urea-N top-dressed at 4 different dates on the protein content of hard red winter wheat, Columbus Experiment Field.

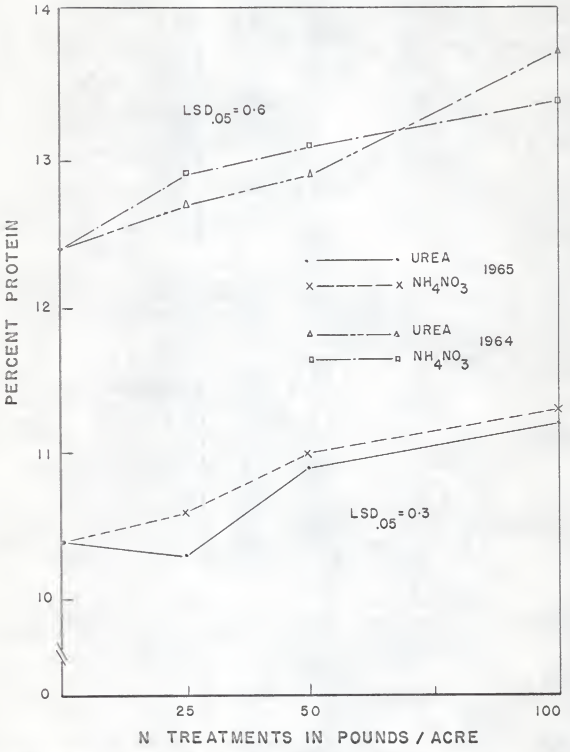

Fig. 19. The effects of drilled N treatments employing 2 N carriers on the protein content of hard red winter wheat, Columbus Experiment Field.

SUMMARY AND CONCLUSIONS

Results of this study have indicated that urea is an effective nitrogenous fertilizer for wheat. Top-dressed applications of this material at five Kansas locations were seemingly as effective as treatments applied before seeding. Comparisons of urea and ammonium nitrate did not reveal any consistent difference in the abilities of these two carriers to supply nitrogen to wheat. Comparisons of these two carriers were applicable only to the pre-seeding applications of nitrogen.

Wheat yields were directly related to the rate of nitrogen fertilization. Responses to nitrogen fertilization at the rates of 25, 50, and 100 pounds of N per acre were not uniform among the five sites as would be expected nor were the results completely translatable from one year to the next. Variations in response to nitrogen fertilization were due to both soil and climatological conditions.

The time of urea top-dressing was important in regard to yield response. When the time of N application was postponed until the heads were in the boots, significant reductions in yield were observed at the Sandyland field (St. John) and the Evans farm in Reno county. Other dates of nitrogen application were about equal in respect to yield responses.

Phosphorus fertilization produced significant yield responses at the Evans farm, St. John, Newton, and Columbus. The effects of P and K on yields, however, could not be separated at the Columbus site due to the simultaneous application of both nutrients.

The protein content of the grain was in all cases directly related to the rate of N fertilization. There was seemingly no difference between the abilities of the two nitrogen carriers to influence the quality of the grain in this respect. Delayed top-dressings of nitrogen, while having a somewhat detrimental effect on yields at some locations, generally tended to produce wheat of a higher protein content. Phosphorus applications tended to lower the protein content of the grain.

Test weight of the grain was in some instances inversely related to the rate of nitrogen fertilization. This relationship, however, was varied between sites, dates of N application, and crop years. Yellow berry was inversely related to nitrogen fertilization.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Drs. Larry S. Murphy and Floyd W. Smith for the suggestion of the problem and for assistance given throughout the course of the study. Sincere appreciation is also extended to Dr. Majel McMaster of the Department of Flour and Feed Milling Industries for her help in the preparation of the manuscript, and to my colleague, Mr. Frank Wooding, for his help in the qualitative and chemical analyses of the grains.

Special gratitude is expressed to Davison Chemical Division of W. R. Grace and Company for their chemical and financial assistance in this work.

Grateful appreciation is expressed to my wife, Zenaida, and daughters, Aileen and Mary Ann, for encouragement and inspiration throughout the course of the study. Sincere gratitude is also expressed to those, who in one way or another, have given assistance in the execution of the study.

LITERATURE CITED

1. Almeida, L. A. V., and J. Q. dos Santos.
Late application of nitrogen to wheat: five years of field experiments. An. Inst. Sup. Agron. Lisboa, 24:163-174. 1962.

2. Ames, J. W., Boltz, G. E., and J. A. Stenius.
Effect of fertilizers on the physical and chemical properties of wheat. Ohio Agri. Exp. Sta. Bul. 243, 564-587. 1912.

3. Bayfield, E. G.
The influence of climate, soil and fertilizers upon quality of soft winter wheat. Ohio Agri. Exp. Sta. Bul. 2139. 1936.

4. Berliner, J. F. T.
Crystal Urea - Industrial Development and Properties. Industrial and Engineering Chemistry. 28:517-522. May, 1935.

5. Black, C. A.
Soil-Plant Relationships. John Wiley and Sons, Inc. New York. pp. 179-247. 1957.

6. Bracken, A. F.
Effect of various soil treatments on nitrates, soil moisture, and yield of winter wheat. Soil Science. 50:175-188. 1940.

7. Brioux, Ch.
Influence of urea, used as a fertilizer, on the reaction of the soil. Academic Des Sciences, Comptes Rendur. 179:915-917 (1924). C.A. 19:1025.

8. Call, L. E., Green, R. M., and C. O. Swanson.
How to grow and market high-protein wheat. Kansas Agri. Exp. Sta. Circular 114. June, 1925.

9. Carpenter, R. W., Haas, H. J., and E. F. Miles.
Nitrogen uptake of wheat in relation to nitrogen content of soil. Agron. Jour. 44:420-423. 1952.

10. Conrad, J. P.
Hydrolysis of urea in soils by thermolabile catalysis. Soil Science. 49:253-263. 1940.

11. Conrad, J. P.
The nature of the catalyst causing the hydrolysis of urea in soils. Soil Science. 50:119-134. 1940.

12. Conrad, J. P.
The occurrence and origin of urease-like activities in the soil. Soil Science. 54:367-380. 1942.

13. Conrad, J. P.
Enzymatic versus microbial concepts of urea hydrolysis in soils. Agron. Jour. 34:1102-1113. 1942.

14. Conrad, J. P. and C. N. Adams.
Retention by soils of the nitrogen of urea and some related phenomena. Agron. Jour. 32:48-54. 1940.

15. Davidson, J.
The effect of nitrates applied at different stages of growth on the yield, composition, and quality of wheat. Agron. Jour. 14:118-122. 1922.

16. Dumenil, Lloyd.
It's smart to fall fertilize. Successful Farmer 50:(10)56,92. Oct., 1953.

17. Eagle, D. J.
Responses of winter wheat to nitrogen and soil nitrogen status. Jour. Sci. Food Agri. 14:391-394. 1963.

18. Ensminger, L. E. and R. W. Pearson.
Soil Nitrogen. Advances in Agronomy. Amer. Soc. Agron. 2:87-111. 1950.

19. Federer, W. T.
Experimental Design: Theory and Application. The Macmillan Co., New York, N. Y., pp. 114-134. Print 2, 1963.

20. Finney, K. F., Meyer, J. W., Smith, F. W., and H. C. Fryer.
Effect of foliar spraying of Pawnee wheat with urea solutions on yield, protein content and protein quality. Agron. Jour. 49:341-347. 1957.

21. Food Research Institute. Wheat Studies.
Vol. X, No. 6. The Stanford University. March, 1934.

22. Gasser, J. K. R.
Urea as a fertilizer. Soils and Fertility. XXVII: 175-180. No. 3, 1964.

23. Gibson, T.
Decomposition of urea in soils. Jour. Agri. Sci. 20:549-558. 1930.

24. Heyne, E. G., Smith, F. W., Hobbs, J. A., Stickler, F. C., Anderson, L. E., and H. D. Wilkins.
Growing wheat in Kansas. Kans. Agri. Exp. Sta. Bul. 463. 1964.

25. Hourigan, W. R., and W. A. Seay.
Soil chemistry of fertilizer urea. Kent. Agri. Exp. Sta. Annual Rept. of Dir. 69:37. 1957.

26. Jackson, M. L.
Soil Chemical Analysis. Prentice-Hall, Inc. Englewood Cliffs, N. J. pp. 183-192. 1958.

27. Jones, H. W.
Some transformation of urea and their resultant effect on the soil. Soil Science. 34:281-299. 1932.

28. Laude, H. H.
Growing wheat in Kansas. Kans. Agri. Exp. Sta. Bul. 370. 1955.

29. Leonard, W. H., and J. H. Martin.
Cereal Crops. The Macmillan Co., New York, N. Y. pp. 275-426. Print. 1. 1963.

30. Littler, J. W.
Effect of time and rate of application of urea to wheat. Qd. Jour. Agri. Sci. 20:324-344. 1963.

31. Long, O. H., and C. D. Sherbakoff.
Effect of nitrogen on the yield and quality of wheat. Agron. Jour. 43:320-321. 1951.

32. Long, O. H., and J. A. Ewing.
Fertilizer studies on small grains with special emphasis on the time and rate of nitrogen application. Tenn. Agri. Exp. Sta. Bul. 209. 1949.

33. McNeal, F. H., and D. J. Davis.
Effect of nitrogen fertilization on yield, culm number, and protein content of certain spring wheat varieties. Agron. Jour. 46:375-378. 1954.

34. Meyer, B. S., Anderson, D. B., and R. H. Bohning.
Introduction to Plant Physiology. D. Van Nostrand Co., Inc. 16:327-348. 1963.

35. Millar, C. E.
Soil Fertility. John Wiley and Sons, Inc. New York, N. Y., pp. 103-138. 1959.

36. Miller, Edwin C.
A physiological study of the winter wheat plant at different stages of its development. Kansas Agri. Exp. Sta. Tech. Bul. 47. July, 1939. pp. 42-61.

37. Miller, L. B., and F. C. Bauer.
Soil treatments for winter wheat: a summary of field experiments. Ill. Agri. Exp. Sta. Bul. 503. 1944.

38. Murphy, H. F.
Fertilizing wheat for yield and quality. Okla. Agri. Exp. Sta. Bul. 285. 1945.

39. Murphy, L. S.
Soil reactions of urea. Master of Science Thesis. University of Missouri, Columbia. 1960.

40. Neidig, Ray E., and R. S. Snyder.
The effect of available nitrogen on the protein content and yield of wheat. Univ. Idaho Agri. Exp. Sta. Bul. 1, 1922.

41. Neidig, Ray E., and R. S. Snyder.
The relation of moisture and available nitrogen to the yield and protein content of wheat. Soil Science. 18:173-179. 1924.

42. Parks, W. L.
Soil temperature affects urea use. Crops and Soils. 11:(1)24. Oct., 1958.

43. Reitz, L. P., and H. E. Myers.
Response of wheat varieties to application of superphosphate fertilizer. Agron. Jour. 36:928-936. 1944.

44. Remy, Th.
Fertilization in its relationship to the course of nutrient absorption by plants. Soil Science. 46:187-209. 1938.

45. Roberts, H. F.
Yellow berry in hard winter wheat. Jour. Agri. Res. Vol. XVII, No. 3. 1919.

46. Russel, E. J.
Soil Conditions and Plant Growth. Longmans, Green and Co., Ltd. London. 1950.

47. Salmon, S. C., Mathews, O. R., and R. W. Leukel.
A half century of wheat improvement in the United States. Advances in Agron. V:1-151. 1953.

48. Salmon, S. C., and H. M. Bainer.
Wheat production in Kansas. KSU Extension Service. Ext. Bul. 41. Feb., 1923.

49. Seth, J., Herbert, I. T., and G. K. Middleton.
Nitrogen utilization in high and low protein wheat varieties. Agron. Jour. 52:207-209. 1960.

50. Smith, F. W.
Placing fertilizer for efficient production of small grains. Natl. Jt. Com. Fert. Appli. Proc. 29:59-62. 1953.

51. Smith, F. W., Lindell, D. L., Fortner, L. B., Johnson, J. M., and C. P. Mamaril.
Preliminary report of fertilizer trials with wheat. Kans. State Fert. Handbook. 1962.

52. Snedecor, G. W.
Statistical Methods. The Iowa State University Printing Press. Ames, Iowa. pp. 46, 246-249, 300-303. Ed. 5. 1962.

53. Snyder, H.
Influence of fertilizer on the composition of wheat. Jour. Amer. Chem. Soc. 30:604-608. 1908.

54. Steward, F. C.
Plants at Work: A Summary of Plant Physiology. Cornell University. 8:83-100. 1964.

55. Sullivan, J. T., Kraybill, H. R., Gustafson, C. B., Cutler, G. H., Brinson, G. A., Mulvey, R. R., and G. P. Walker.
Effects of fertilizer application and other cultural practices on some kernel characteristics of winter wheat. Ind. Agri. Exp. Sta. Bul. 432. 1938.

56. Swanson, C. O.
Factors influencing the protein content of wheat. Kans. Agri. Exp. Sta. Rept. 1932-1934:52-53. 1934.

57. Tennessee Agricultural Experiment Station.
The Middle Tennessee Farmers and Homemaker's Inst. July, 1957.

58. Wells, J. P., and S. L. Keogh.
Fertilizer studies for wheat and oats for grain production. Ark. Agri. Exp. Sta. Bul. 677. 1963.

59. Widdowson, F. V., Penny, A., and R. Williams.
Autumn nitrogen for wheat. Jour. Agri. Science. 57:329-334. 1961.

APPENDIX

Table 1. Summary of hard red winter wheat urea fertilizer trials, Richard Evans farm, Hutchinson, 1964.

Treatment	Average % Protein	Average Yield Bu./A.	Average Test Wt. Lbs./Bu.
1. No fertilizer	11.22	35.29	60.0
2. Phosphate only	11.25	44.06	60.1
3. N-25 drilled before seeding - Urea	11.58	43.12	59.8
4. N-50 " " " "	12.08	47.42	60.1
5. N-100 " " " "	13.81	48.62	59.7
6. N-25 drilled before seeding - NH_4NO_3	11.38	44.46	60.2
7. N-50 " " " "	13.21	47.56	59.8
8. N-100 " " " "	14.18	47.88	59.7
9. N-25 topdressed - February 20 - Urea	11.29	43.16	60.0
10. N-50 " " "	11.70	46.72	60.2
11. N-100 " " "	13.14	45.94	59.5
12. N-25 topdressed - March 5 - Urea	10.99	45.10	60.2
13. N-50 " " "	11.76	43.93	59.9
14. N-100 " " "	13.19	45.72	59.4
15. N-25 topdressed - March 24 - Urea	11.95	43.64	59.7
16. N-50 " " "	12.11	42.62	59.7
17. N-100 " " "	13.06	45.82	59.8
18. N-25 topdressed - April 8 - Urea	11.08	40.81	60.1
19. N-50 " " "	11.65	43.41	60.2
20. N-100 " " "	12.96	44.92	59.7
L.S.D.	1.36	3.04	N.S.

Table 2. Summary of hard red winter wheat urea fertilizer trials, Richard Evans farm, Hutchinson, 1965.

Treatment	Ave. % Protein	Ave. Yield Bu./A.	Ave. Test Wt. Lbs./Bu.	Ave. % Yellow berry	Ave. Wt. per 100 Kernels g
1. No fertilizer	11.0	29.6	61.1	5.8	3.127
2. Phosphate only	10.2	36.2	61.8	17.2	3.278
3. N-25 drilled before seeding - Urea	10.5	38.8	62.0	13.5	3.335
4. N-50 " " " "	10.9	41.8	62.2	7.0	3.354
5. N-100 " " " "	11.8	44.2	61.6	2.0	3.284
6. N-25 drilled before seeding - NH_4NO_3	10.4	39.2	62.1	9.2	3.300
7. N-50 " " " "	11.2	40.0	61.7	4.5	3.282
8. N-100 " " " "	11.5	44.0	61.7	2.0	3.202
9. N-25 topdressed - February 19 - Urea	11.1	38.1	62.0	6.8	3.328
10. N-50 " " "	11.4	39.9	62.0	4.5	3.353
11. N-100 " " "	12.4	41.4	61.7	1.5	3.332
12. N-25 topdressed - March 12 - Urea	10.9	39.7	62.0	5.8	3.286
13. N-50 " " "	11.5	40.6	61.8	4.2	3.274
14. N-100 " " "	12.6	42.0	61.5	1.8	3.214
15. N-25 topdressed - April 12 - Urea	11.0	39.7	62.0	7.8	3.332
16. N-50 " " "	11.5	39.8	61.8	4.0	3.324
17. N-100 " " "	12.4	41.1	61.3	1.8	3.278
18. N-25 topdressed - May 5 - Urea	11.5	40.3	62.1	6.8	3.372
19. N-50 " " "	12.5	38.4	61.7	2.2	3.348
20. N-100 " " "	13.3	38.5	61.6	2.0	3.283
L.S.D.	0.4	2.7	0.4	4.3	0.118

Table 3. Summary of hard red winter wheat urea fertilizer trials, Sandyland Experiment Field, St. John, 1964.

Treatment	Average % Protein	Average Yield Bu./A.	Average Test Wt. Lbs./Bu.	Average % Yellow berry
1. No fertilizer	11.82	30.94	61.3	7.2
2. Phosphate only	11.74	35.40	61.3	11.2
3. N-25 drilled before seeding - Urea	12.15	36.92	61.1	6.5
4. N-50 " " " "	12.34	38.12	61.0	4.0
5. N-100 " " " "	13.14	37.71	60.7	3.5
6. N-25 drilled before seeding - NH_4NO_3	12.11	37.71	61.2	5.0
7. N-50 " " " "	13.17	37.54	60.5	3.5
8. N-100 " " " "	14.66	37.64	60.1	1.5
9. N-25 topdressed - February 20 - Urea	12.62	35.26	61.0	5.5
10. N-50 " " "	12.65	36.33	61.0	4.0
11. N-100 " " "	13.61	36.13	61.0	2.8
12. N-25 topdressed - March 5 - Urea	12.21	37.22	61.5	8.2
13. N-50 " " "	13.68	36.37	61.0	7.2
14. N-100 " " "	13.84	38.71	60.7	4.0
15. N-25 topdressed - March 24 - Urea	12.31	35.74	61.2	5.8
16. N-50 " " "	12.99	36.02	60.6	5.0
17. N-100 " " "	13.79	37.05	60.6	4.8
18. N-25 topdressed - April 8 - Urea	12.55	36.46	61.3	4.5
19. N-50 " " "	13.41	36.75	61.2	3.5
20. N-100 " " "	13.81	37.81	61.1	3.5
L.S.D.	0.72	N.S.	N.S.	4.6

Table 4. Summary of hard red winter wheat urea fertilizer trials, Sandyland Experiment Field, St. John, 1965.

Treatment	Ave. % Protein	Ave. Yield Bu./A.	Ave. Test Wt. Lbs./Bu.	Ave. % Yellow berry	Ave. Wt. per 100 Kernels g
1. No fertilizer	10.1	29.8	60.4	6.5	2.911
2. Phosphate only	10.2	23.1	59.4	6.5	2.780
3. N-25 drilled before seeding - Urea	10.2	27.6	59.6	3.8	2.859
4. N-50 " " " "	10.3	32.6	60.5	5.2	2.927
5. N-100 " " " "	11.1	34.0	59.4	3.5	2.805
6. N-25 drilled before seeding - NH_4NO_3	10.2	29.8	60.1	7.5	2.819
7. N-50 " " " "	10.3	33.4	60.7	4.0	2.805
8. N-100 " " " "	11.2	41.0	60.8	2.0	2.964
9. N-25 topdressed - February 19 - Urea	10.2	31.9	60.7	5.5	2.996
10. N-50 " " "	10.4	35.8	60.7	2.8	2.971
11. N-100 " " "	10.7	38.5	61.0	1.2	3.040
12. N-25 topdressed - March 12 - Urea	9.9	32.1	60.4	6.0	2.913
13. N-50 " " "	10.8	38.3	60.6	2.8	3.044
14. N-100 " " "	11.2	37.8	59.5	1.8	2.758
15. N-25 topdressed - April 12 - Urea	10.2	29.2	59.8	4.2	2.807
16. N-50 " " "	10.5	32.4	59.1	3.0	2.775
17. N-100 " " "	11.9	34.0	58.3	1.8	2.785
18. N-25 topdressed - May 5 - Urea	10.8	25.5	59.5	3.2	2.790
19. N-50 " " "	11.2	26.6	59.6	2.8	2.939
20. N-100 " " "	12.3	22.2	57.8	1.2	2.726
L.S.D.	0.6	6.6	1.3	2.4	0.210

Table 5. Summary of hard red winter wheat urea fertilizer trials, Ashland Agronomy Farm, 1964.

Treatment	Average % Protein	Average Yield Bu./A.	Average Test Wt. Lbs./Bu.
1. No fertilizer	10.23	47.36	58.2
2. Phosphate only	10.35	41.78	58.0
3. N-25 drilled before seeding - Urea	10.40	46.30	58.6
4. N-50 " " " "	12.10	45.54	58.7
5. N-100 " " " "	12.90	41.02	59.4
6. N-25 drilled before seeding - NH_4NO_3	11.36	46.36	58.9
7. N-50 " " " "	11.77	45.20	58.9
8. N-100 " " " "	13.21	41.26	58.9
9. N-25 topdressed - February 27 - Urea	11.38	43.09	59.0
10. N-50 " " "	11.33	44.02	58.9
11. N-100 " " "	12.72	40.92	58.9
12. N-25 topdressed - March 12 - Urea	11.31	41.57	58.9
13. N-50 " " "	11.90	43.92	59.1
14. N-100 " " "	13.34	39.95	59.1
15. N-25 topdressed - March 30 - Urea	10.27	48.47	58.3
16. N-50 " " "	11.65	49.16	59.1
17. N-100 " " "	13.52	43.40	59.1
18. N-25 topdressed - April 15 - Urea	11.29	50.68	59.1
19. N-50 " " "	11.88	49.92	59.0
20. N-100 " " "	12.70	44.37	59.1
L.S.D.	1.18	N.S.	0.56

Table 6. Summary of hard red winter wheat urea fertilizer trials, Manhattan Agronomy Farm, 1965.[1/]

Treatment	Ave. % Protein	Ave. Yield Bu./A.	Ave. Test Wt. Lbs./Bu.	Ave. % Yellow berry	Ave. Wt. per 100 Kernels g
1. No fertilizer	13.3	31.8	59.8	8.0	2.384
2. Phosphate only	12.0	37.2	59.6	12.0	2.459
3. N-25 drilled before seeding - Urea	12.6	29.7	60.3	6.5	2.490
4. N-50 " " " "	13.4	19.8	59.1	2.5	2.435
5. N-100 " " " "	13.9	30.3	59.8	1.5	2.479
6. N-25 drilled before seeding - NH_4NO_3	12.5	24.7	60.0	5.0	2.462
7. N-50 " " " "	13.9	24.8	59.0	3.5	2.325
8. N-100 " " " "	13.2	28.5	59.5	1.5	2.628
9. N-25 topdressed - February 19 - Urea	13.2	26.8	59.6	5.5	2.319
10. N-50 " " "	13.3	30.1	59.4	3.5	2.363
11. N-100 " " "	14.5	28.3	59.6	1.5	2.368
12. N-25 topdressed - March 12 - Urea	13.4	24.8	59.5	7.0	2.431
13. N-50 " " "	14.1	27.3	60.1	3.5	2.460
14. N-100 " " "	14.9	28.8	59.7	2.0	2.242
15. N-25 topdressed - April 12 - Urea	13.8	28.5	60.0	7.5	2.346
16. N-50 " " "	14.3	29.6	59.8	5.0	2.372
17. N-100 " " "	14.2	31.8	59.9	2.5	2.365
18. N-25 topdressed - May 5 - Urea	13.4	26.6	60.2	3.5	2.446
19. N-50 " " "	13.9	36.1	60.1	5.5	2.496
20. N-100 " " "	14.4	28.3	60.0	3.5	2.469
L.S.D.	N.S.	N.S.	N.S.	3.9	N.S.

1/ Two reps only were harvested for chemical and qualitative analysis due to severe damage caused by winter kill and weeds.

Table 7. Summary of hard red winter wheat urea fertilizer trials, Newton Experiment Field, 1964.

	Treatment	Average % Protein	Average Yield Bu./A.	Average Test Wt. Lbs./Bu.	Average % Yellow berry
1.	No fertilizer	10.22	30.49	60.5	12.6
2.	Phosphate only	9.94	34.96	59.8	8.3
3.	N-25 drilled before seeding - Urea	10.35	42.18	60.6	7.3
4.	N-50 " " " "	10.81	42.60	60.3	4.3
5.	N-100 " " " "	12.25	47.79	60.8	.6
6.	N-25 drilled before seeding - NH_4NO_3	10.43	40.20	60.4	9.0
7.	N-50 " " " "	11.45	48.20	61.1	3.3
8.	N-100 " " " "	13.09	45.22	60.9	1.3
9.	N-25 topdressed - February 20 - Urea	10.52	41.03	60.7	7.0
10.	N-50 " " "	10.90	47.43	61.1	9.6
11.	N-100 " " "	13.09	47.56	60.6	2.0
12.	N-25 topdressed - March 5 - Urea	10.34	44.48	60.3	8.0
13.	N-50 " " "	11.53	47.58	61.0	2.3
14.	N-100 " " "	12.35	50.60	60.8	.6
15.	N-25 topdressed - March 24 - Urea	10.87	42.32	60.9	9.0
16.	N-50 " " "	11.57	45.91	60.9	4.6
17.	N-100 " " "	12.86	49.08	60.8	3.6
18.	N-25 topdressed - April 8 - Urea	10.41	42.69	60.9	6.6
19.	N-50 " " "	12.16	45.45	61.0	3.6
20.	N-100 " " "	12.71	49.59	60.8	3.0
L.S.D.		0.70	4.03	0.53	N.S.

Table 8. Summary of hard red winter wheat urea fertilizer trials, Newton Experiment Field, 1965.

Treatment	Average % Protein	Average Test Wt. Lbs./Bu.	Average % Yellow berry	Ave. Wt. per 100 Kernels g
1. No fertilizer	11.6	59.1	8.2	2.992
2. Phosphate only	11.9	59.9	9.0	3.150
3. N-25 drilled before seeding - Urea	11.6	60.6	9.0	3.132
4. N-50 " " " "	11.5	60.6	7.2	3.289
5. N-100 " " " "	13.0	59.8	2.8	3.146
6. N-25 drilled before seeding - NH_4NO_3	11.4	60.4	9.8	3.184
7. N-50 " " " "	11.5	60.5	7.5	3.178
8. N-100 " " " "	12.3	60.3	3.5	3.246
9. N-25 topdressed - February 19 - Urea	12.2	60.0	5.8	3.104
10. N-50 " " "	12.7	59.3	4.0	3.120
11. N-100 " " "	13.7	59.3	1.2	3.143
12. N-25 topdressed - March 12 - Urea	12.2	59.5	4.0	3.175
13. N-50 " " "	12.9	60.1	3.8	3.193
14. N-100 " " "	13.8	59.2	2.0	3.119
15. N-25 topdressed - April 12 - Urea	12.4	59.9	5.5	3.137
16. N-50 " " "	13.0	59.6	3.0	3.186
17. N-100 " " "	13.9	59.2	1.8	3.130
18. N-25 topdressed - May 5 - Urea	12.4	59.6	4.2	3.176
19. N-50 " " "	13.4	59.0	3.0	3.139
20. N-100 " " "	14.3	58.4	2.0	3.124
L.S.D.	0.3	1.0	2.6	N.S.

Table 9. Summary of hard red winter wheat urea fertilizer trials, Columbus Experimental Field, 1964.

Treatment	Average % Protein	Average Yield Bu./A.	Average Test Wt. Lbs./Bu.	Average % Yellow berry
1. No fertilizer	12.11	33.32	59.1	5.8
2. Phosphate and K	12.37	40.68	58.8	3.5
3. N-25 drilled before seeding - Urea	12.74	40.84	58.0	1.5
4. N-50 " " " "	12.94	41.95	58.6	1.5
5. N-100 " " " "	13.76	40.13	58.1	.2
6. N-25 drilled before seeding - NH_4NO_3	12.95	39.64	58.4	1.0
7. N-50 " " " "	13.11	41.88	58.3	1.2
8. N-100 " " " "	13.41	40.40	58.2	.8
9. N-25 topdressed - January 15 - Urea	13.08	41.26	57.8	1.0
10. N-50 " " "	13.31	42.64	58.1	.8
11. N-100 " " "	13.48	42.18	57.9	.8
12. N-25 topdressed - February 15 - Urea	12.84	39.33	57.9	1.5
13. N-50 " " "	13.08	40.92	58.1	2.8
14. N-100 " " "	13.42	41.36	58.0	.5
15. N-25 topdressed - March 1 - Urea	12.79	41.19	58.3	1.5
16. N-50 " " "	12.88	41.64	58.1	1.8
17. N-100 " " "	13.20	39.74	58.6	1.0
18. N-25 topdressed - March 15 - Urea	12.87	42.30	57.9	2.0
19. N-50 " " "	13.15	41.51	58.3	.8
20. N-100 " " "	13.49	39.54	58.2	.8
L.S.D.	0.55	3.04	0.66	2.2

Table 10. Summary of hard red winter wheat urea fertilizer trials, Columbus Experimental Field, 1965.

Treatment	Average % Protein	Average Yield Bu./A.	Average Test Wt. Lbs./Bu.	Ave. Wt. per 100 Kernels g
1. No fertilizer	11.2	41.6	58.8	2.254
2. Phosphate and K	10.4	54.9	59.4	2.354
3. N-25 drilled before seeding - Urea	10.3	56.2	59.6	2.410
4. N-50 " " " "	10.9	62.0	59.8	2.360
5. N-100 " " " "	11.2	58.1	59.8	2.392
6. N-25 drilled before seeding - NH_4NO_3	10.6	57.6	59.5	2.370
7. N-50 " " " "	11.0	49.0	59.5	2.317
8. N-100 " " " "	11.3	56.9	59.8	2.332
9. N-25 topdressed - January 15 - Urea	10.6	55.8	59.5	2.425
10. N-50 " " "	11.0	62.9	59.8	2.370
11. N-100 " " "	11.6	57.8	59.7	2.245
12. N-25 topdressed - February 15 - Urea	10.5	56.2	59.7	2.334
13. N-50 " " "	10.8	57.2	59.7	2.343
14. N-100 " " "	11.5	56.4	60.0	2.330
15. N-25 topdressed - March 1 - Urea	10.8	59.2	59.5	2.315
16. N-50 " " "	11.0	59.6	59.8	2.333
17. N-100 " " "	11.8	58.0	59.6	2.569
18. N-25 topdressed - March 15 - Urea	10.4	62.2	59.5	2.332
19. N-50 " " "	10.8	58.6	59.4	2.358
20. N-100 " " "	11.9	55.3	59.9	2.291
L.S.D.	0.3	6.4	0.3	N.S.

Table 11. Rainfall at the experiment locations, 1963.

Month	Ashland Agronomy Farm	Newton Experiment Field	Sandyland Experiment Field	R. Evans Farm Hutchinson	Columbus Experiment Field
January	No record	.75	.32	.39	1.00
February	No record	.00	.00	Trace	.00
March	.10 (inc.)	1.27	.83	1.82	2.17
April	.89	.29	.33	.33	1.23
May	1.69	2.95	1.39	2.07	3.44
June	3.40	1.77	5.19	2.92	3.61
July	1.32	7.70	2.75	4.07	3.58
August	1.88	1.39	2.95	2.61	1.61
September	2.32	3.49	4.06	9.04	0.63
October	1.99	3.62	1.81	2.55	0.05
November	.69	1.03	.09	1.05	0.15
December	.29	.54	.55	.20	.34
Total	14.57	24.80	20.27	27.06	17.81

Table 12. Rainfall at the experiment locations, 1964.[1]

Month	Ashland/ Manhattan Agronomy Farm	Newton Experiment Field	Sandyland Experiment Field	R. Evans Farm Hutchinson	Columbus Experiment Field
January	--	0.55	0.12	0.54	0.57
February	--	0.69	0.30	0.34	1.82
March	--	1.22	0.41	0.95	2.67
April	4.31	2.83	1.45	0.81	8.50
May	2.00	6.02	3.68	4.42	4.20
June	5.57	4.41	1.36	1.63	11.42
July	3.64	2.93	1.08	1.46	0.52
August	3.22	8.16	4.23	6.48	6.19
September	2.03	3.42	2.70	2.45	1.71
October	.26	0.98	0.30	0.25	0.78
November	3.64	2.10	4.06	4.48	4.68
December	.98	3.29	0.46	.90	1.21
Total	25.65	36.60	20.15	24.71	44.27

[1]The rainfall data for Ashland Agronomy Farm were only available until June. Thereafter, data were taken from Manhattan Agronomy Farm, the experiment site for 1965.

Table 13. Rainfall at the experiment locations, 1965.[1/]

Month	Manhattan Agronomy Farm	Newton Experiment Field	Sandyland Experiment Field	R. Evans Farm Hutchinson	Columbus Experiment Field
January	1.92	2.63	0.58	0.26	1.98
February	1.51	2.42	0.88	0.63	0.94
March	2.06	.41	0.06	0.22	2.04
April	1.48	2.47	2.40	2.07	5.30
May	1.93	3.69	3.50	3.66	3.34
Total	8.90	11.62	7.42	6.84	13.60

[1/] At the St. John Experiment Field, 10.44 inches of precipitation was recorded from the period June 1-6, 1965; 9.78 inches in Hutchinson; 4.15 inches in Columbus from June 1-20.

Table 14. Average temperatures at the experiment locations, 1963 (^{o}F).

Month	Ashland Agronomy Farm		Newton Experiment Field		Sandyland Experiment Field		R. Evans Farm Hutchinson		Columbus Experiment Field	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
January	9.5	29.1	10.9	32.1	10.1	36.5	10.4	35.3	15.3	39.5
February	21.4	46.9	22.8	49.1	24.6	54.9	23.5	52.9	23.9	49.2
March	34.8	60.5	35.8	62.6	36.5	64.7	35.5	63.3	39.0	65.5
April	45.8	71.9	45.8	73.8	45.3	74.2	44.8	73.1	50.7	74.5
May	55.0	76.7	54.7	79.6	56.5	82.1	55.7	81.5	56.8	79.8
June	66.3	89.1	66.4	91.8	65.3	89.3	65.9	91.4	66.3	90.6
July	70.6	93.5	70.2	94.4	70.6	95.0	70.2	94.9	68.8	93.6
August	68.0	92.4	68.7	94.2	67.9	93.6	68.4	94.5	67.4	93.4
September	60.9	84.0	60.6	82.9	61.5	83.6	61.7	82.4	60.0	88.9
October	54.6	82.0	54.0	82.1	53.8	80.7	53.8	80.7	53.5	87.9
November	35.5	59.7	34.8	60.1	32.9	60.6	34.8	59.3	34.0	64.0
December	14.7	36.1	14.9	35.5	16.2	38.0	16.2	37.1	16.4	39.4

Table 15. Average temperature at the experiment locations, 1964 and 1965 (^{o}F).[1/]

Month	Ashland/ Manhattan Agronomy Farm		Newton Experiment Field		Sandyland Experiment Field		R. Evans Farm Hutchinson		Columbus Experiment Field	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1964										
January	22.4	48.1	22.1	49.6	21.4	51.2	22.7	50.6	25.0	52.7
February	22.7	46.7	23.2	46.1	22.5	47.4	24.0	47.8	26.4	49.9
March	28.0	55.1	27.7	56.3	26.4	56.7	27.7	56.5	31.2	58.2
April	45.5	69.4	45.6	70.5	43.4	72.1	44.4	71.1	50.5	73.3
May	58.1	80.7	57.2	80.9	55.6	82.9	55.3	81.6	58.4	79.7
June	62.6	84.7	62.9	88.3	60.2	88.9	62.3	90.0	64.4	84.3
July	69.5	95.0	70.1	98.6	68.9	98.0	71.1	99.6	67.4	92.8
August	63.3	85.1	64.0	87.9	62.2	88.4	65.2	89.4	43.8	88.7
September	57.4	79.8	59.1	81.5	58.1	81.2	59.5	82.1	59.3	82.5
October	39.0	70.8	43.7	71.5	43.1	71.1	43.3	72.8	43.4	74.0
November	35.6	56.0	37.6	54.8	35.4	55.2	37.1	55.2	41.5	62.3
December	17.4	38.6	20.6	39.8	20.6	42.1	20.8	41.5	26.0	46.6
1965										
January	16.5	40.1	22.1	44.5	21.9	47.6	23.1	46.7	26.3	49.4
February	15.5	38.3	21.1	45.1	19.9	45.1	20.8	46.2	25.1	50.8
March	21.4	41.0	23.0	46.0	22.4	46.9	23.5	47.7	26.7	48.6
April	42.7	67.6	47.0	71.3	44.9	72.1	45.8	71.9	49.4	74.5
May	57.2	79.0	56.5	77.9	55.8	79.7	55.7	78.2	58.9	80.5

[1/]The temperature data for Ashland Agronomy Farm were only available until June. The succeeding data were taken from Manhattan Agronomy Farm.

EVALUATION OF SOLID UREA FERTILIZER
AS A SOURCE OF NITROGEN FOR WHEAT

by

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Philippines, 1961

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

ABSTRACT

A two-year investigation of the effectiveness of urea as a nitrogenous fertilizer for wheat was conducted at five locations in the state of Kansas. Summarized data from both crop years (1964 and 1965) reveal that urea is an effective source of nitrogen for wheat. No consistent differences were found between the effects of drilled applications of urea and ammonium nitrate on wheat yields or grain quality. Top-dressed applications of urea nitrogen were as effective as treatments incorporated into the soil prior to seeding.

Wheat yields and protein content of the grain were found to be directly related to the rate of nitrogen fertilization. Protein content of the grain was enhanced by late top-dressings of nitrogen.