1957

Utilization of Nitrogen Fertilizer by Crops as Influenced by Time of Application, Carriers and Crop Residues

Wayne E. Lamke

UTILIZATION OF NITROGEN FERTILIZER BY CROPS AS INFLUENCED BY TIME OF APPLICATION, CARRIERS AND CROP RESIDUES

By

Wayne E. Lamke

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science at South Dakota
State College of Agriculture
and Mechanic Arts

June, 1957

UTILIZATION OF NITROGEN FERTILIZER BY CROPS AS INFLUENCED

BY TIME OF APPLICATION, CARRIERS AND CROP RESIDUES

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Head of the Major Department

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. Leo F. Puhr, Agronomist, Dr. W. W. Worzella, Head of the Agronomy Department, Dr. Fred E. Shubeck, Associate Agronomist, and the Agronomy staff members for their supervision and kind encouragement in conducting this study. Thanks are due to the Nitrogen Division, Allied Chemical & Dye Corporation for providing the fellowship under which this work was conducted.

WEL

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The nitrogen status of South Dakota soils was once very high, but due to our intensive type of farming, the supply of this essential element is rapidly being exhausted. It has been estimated that thirty to forty percent of the original nitrogen content has been lost as a result of farming, erosion, and various other factors. This continuous removal of nitrogen, primarily through cropping, has caused pronounced and widespread nitrogen deficiency symptoms to show up in many areas of the state. These visual symptoms and the resulting low crop yields have aroused considerable interest in the use of nitrogen fertilizer. As the use of fertilizer increases, more attention should be placed on methods of obtaining maximum benefits from this applied nitrogen. It is the purpose of this study to investigate the effect of various fertilizer practices on corn and small grain production in southeastern and east central South Dakota. Some of the practices considered in this study were time of application, carry-over, carriers, and crop residue utilization.

REVIEW OF LITERATURE

Influence of Time of Application of Nitrogen Fertilizer

The problem of fall and spring applied fertilizers has received considerable attention during the past decade. Since fall application involves placing the fertilizer in the soil several months ahead of spring application, the problem resolves itself into the fate of the fertilizer nutrients during this period. Nelson and Uhland (15) reviewed the effect of such factors as leaching, temperature, rainfall, and loss due to erosion on fall applied fertilizer. Their findings show that in an area such as South Dakota, the main loss of nutrients may be due to erosion resulting from rainfall and/or thawing of snow on partially frozen soil, this being especially true on irregular terrain. Their general conclusions were that losses from fall applied fertilizer decreased from southeast to northwest. However, it has been reported that as far south as Mississippi, the time of applying nitrogen fertilizer had very little effect on corn yields if sandy soils were avoided (2). Larsen and Kohnke (10) in Indiana found no significant difference between fall and spring application of 8-8-8 when applied at rates of 1000 and 2000 pounds per acre on Miami sandy loam, a well drained soil, and Crosby silt loam, a poorly drained soil. However, on Vigo silt loam, a very poorly drained soil, fall application of fertilizer resulted in significantly lower yields than spring application. It was their belief that these lower yields were due to poor structural conditions which resulted from alternate freezing and thawing during the winter and a heavy weed infestation on the fall plots. MacGregor (12) noted from his work at six different locations in southeastern Minnesota that fertilizer broadcast on plowed land in the fall was as effective as spring application in increasing corn yields. He concluded that on soils of medium to heavy texture, where leaching is of minor importance, little or no fertilizer was lost even when lying on or near the soil surface during the winter months. Pesek (17) in Iowa studied the effects of applying 40 pounds of nitrogen on corn in the fall and spring. The responses to nitrogen were small compared to those which might be expected from a 40 pound application and therefore, the evidence regarding fall and spring applied nitrogen was considered inconclusive. Brage (4) conducted a number of experiments comparing fall and spring application of fertilizer in western South Dakota from 1951 to 1954. He worked with alfalfa, crested wheatgrass, winter and spring wheat, barley and oats. Alfalfa, which involved only phosphate, did not show a significant difference in yield due to time, but the trend was in favor of fall application. There were definite differences in yield of crested wheatgrass with regard to time of application. The seed yield was significantly higher for fall application as compared to spring application; however, there was no significant difference in yield of forage. There appeared to be a definite advantage in spring application of nitrogen in regard to protein content of the grass, especially at the 160 pound level of nitrogen. Fall application of 40 and 60 pounds of nitrogen increased the yield of winter wheat;

spring application increased the protein content without increasing the yield. In the case of barley and oats, it seemed to make little difference as to when the fertilizer was applied.

Residual Effect of Nitrogen Fertilizers

There has been some recent evidence that grain crops may not use all the fertilizer that is applied the first year and thus a certain portion is carried over and utilized by the following crop. Paschal and French (16) in their economic analysis of some fertilizer rate experiments, reported that in Washington the residual response of irrigated corn to 180 pounds of nitrogen was sufficient to pay the cost of the original fertilizer. In their analysis of experiments conducted at Scottsbluff, Nebraska, in 1951, they considered that the residual response of irrigated corn to an original 120 pound application would pay for approximately 80 pounds of nitrogen. Two similar experiments conducted in 1952 were analysed and it was noted that residual nitrogen from a 120 pound application made the previous year, increased corn yields to a point where the increase payed for the original nitrogen and returned more than $25 per acre. Pesek and Dumenil (18) found that under Iowa conditions on silt loams and soils of heavier texture, the average residual effect of moderate amounts of nitrogen, applied to corn, was about 25 percent of the original application, when measured with oats the next year. It was their opinion that perhaps following a dry year, the residual average may be near 30 percent and following a wet year it would be below 20 percent. In one particular experiment, where corn followed corn, they reported increases of 7, 10, and 17 bushels of corn from the residual effect of 40, 80, 120 pounds of nitrogen respectively. The data of Stanford (25) at Iowa indicated that 60 pounds of nitrogen plowed under for corn gave a significant increase in oat yields the following year. He also noted that carry-over from 30 to 60 pound rates of nitrogen applied as side-dressing on corn, increased oat yields significantly the succeeding year. In an experiment conducted at Cottonwood in western South Dakota from 1950 to 1952, it was reported that yields of barley were increased 20 bushels in 1951 by the carry-over from 140 pounds of nitrogen applied on winter wheat in the fall of 1949 (30). It was also noted in this same experiment, that spring wheat in 1952 did not respond significantly to the nitrogen applied in 1949.

Efficiency of Nitrogen Carriers

Information concerning the efficiency of nitrogen carriers is somewhat limited in its scope. Most of the work has been confined primarily to comparing anhydrous ammonia to ammonium nitrate (2) (8) (24). Hammons (8) from Mississippi reported that anhydrous ammonia was as efficient as ammonium nitrate in the production of oats, either for grain or grazing. Andrews, et al. (2) also of Mississippi concluded that anhydrous ammonia, as a source of nitrogen for corn, was as good as ammonium nitrate. They also noted that if depth of placement and uniformity of application were factors in crop production, anhydrous ammonia may have some advantages over ammonium nitrate. Their opinions were based on the results of thirteen experiments. Smith (24) studied the effects of anhydrous ammonia and ammonium nitrate on winter wheat at two different locations in Kansas and the results indicated no significant differences in the efficiency of the two nitrogen carriers. It was the recommendation of Rhoades, et al. (22) in Nebraska, that solid nitrogen carriers, such as ammonium nitrate and urea, might be broadcast prior to plowing or applied as a side-dressing on irrigated corn and that anhydrous ammonia should be applied either prior to or after the corn has been planted. Viets, et al. (27) in Washington studied the efficiency of five nitrogen carriers applied at three rates on the yield of corn. The carriers used were anhydrous ammonia, ammonium nitrate, urea, ammonium sulfate, and calcium nitrate. The data showed significant differences among carriers, but they attributed this largely to the yield depression caused by the calcium nitrate; the yields resulting from the remaining four carriers were statistically equal.

Influence of Nitrogen Fertilizer Applied with Straw on Crop Yields

It has been realized for a long time that applications of low quality crop residues have a harmful effect on the crop immediately following. There have been many experiments conducted to account for this condition. Hutchinson (9) reported that applications of carbohydrates to soils caused a decrease in soil nitrates. He found that an application of hay dust and straw at once lowered the amounts of ammonia and nitrate, but after several months, the amounts of these two elements began to increase. It has been clearly shown by Martin

(13), Scott (23), and others (1) (6) (11) (14) that additions of straw or other celluloses causes a very serious tie-up of soil nitrogen and a consequent reduction in crop yields. It was believed once that the loss of soil nitrates was due to denitrification brought about by the increased activity of micro-organisms which were favored by the added plant material. This theory was soon replaced by the supposition that soil organisms immobilize soil nitrogen when organic materials are applied. Doryland (7) conducted some very extensive experiments to show that soil organisms may become competitors to crops for the supply of available plant nutrients. It was his opinion that the disturbing effect of crop residue was primarily due to the excess energy material which caused a marked temporary increase of micro-organisms and a consequent assimilation of soil nitrogen, but once the residue was decomposed, there was a liberation of this plant food. The work of Brown and Allison (5) was in agreement with that of Doryland. They found that an application of low carbon-nitrogen ratio materials, such as rotted manure and legume hay, increased the yields of oats whereas wide ratio residues lowered the yields. It was the opinion of Blair and Prince (3) that the availability of nitrogen, following the plow-down of organic residues, was probably a matter of the carbon-nitrogen ratio. They concluded that when straw, with a wide ratio, was supplemented with a source of nitrogen in order to narrow the ratio, little depression of available nitrogen results. On the other hand, if the ratio is sufficiently narrow some nitrates may become available. This was shown in the work of Thomas and Harper (26) who used straw alone and also supplemented with sources of nitrogen. They noted that a combination of straw and supplemental nitrogen increased the available nitrates because of a narrowing of the carbon-nitrogen ratio. There was some variation in opinions as to just what the carbon-nitrogen ratio or nitrogen content of crop residues should be in order to avoid yield injury from their application. Waksman (28) concluded on a theoretical basis that if the nitrogen content of organic matter was about 2 to 2.5 percent, a temporary nitrogen starvation may set in lasting but a few days, followed by the liberation of ammonia. However, if the nitrogen content was below 1 percent, a lasting nitrogen starvation may set in which could be corrected only by the addition of nitrogen fertilizer. Waksman and Tenney (29) concluded that 1.7 percent nitrogen was just sufficient to decompose rye plants. Pinck, et al. (19) noted from their greenhouse studies that in order to offset the effect of wheat straw on nitrogen availability, about 16.5 to 18 pounds of nitrogen, as urea, had to be added per ton of straw applied. They pointed out that sufficient nitrogen must be added to establish a carbon-nitrogen ratio of about 35 to avoid injury by the straw. This ratio corresponds to a nitrogen content of about 1.2 percent for the dry matter. It was their general conclusions that crop residues can be utilized very effectively for maintaining soil organic matter without injury to crops if an adequate quantity of commercial nitrogen is used along with the carbonaceous material.

MATERIALS AND METHODS

Soils of Experimental Fields

Field experiments were conducted on eight different soils located in Brookings, Deuel, Lincoln and Turner Counties. The soils were selected primarily on the basis of their drainage and textural characteristics because it was desirous to conduct certain phases of this study under conditions where loss of nitrogen through leaching could be fully exploited. The physical features of the soils selected for experimental use are briefly described below.

Hecla Sandy Loam The Hecla soils are classified as a Regosol-Chernozem Intergrade. The parent material is Aeolian sand over finer-textured wind or water laid sediments. The surface soil is a very dark gray, very friable, noncalcareous sandy loam of weakly developed fine crumb structure. It is well drained with rapid permeability occuring on nearly level to long sloping topography.

Till Soil An uncorrelated well drained soil developed in glacial till with nearly level topography. This soil is found in Turner County in southeastern South Dakota.

Kranzburg Silt Loam The Kranzburg series includes Chernozem soils developed in thin loess deposits which rests on Iowan till. The thickness of the loess may vary from 20 to about 36 inches. The surface soil is a crumb structured silt loam, neutral to slightly acid, friable and grayish brown to very dark brown or black when moist. The underlying material grades into a slightly weathered, unleached, glacial till with a clay loam texture. Concretions of carbonate of lime are found at depths of 28 to 34 inches. The topography is nearly level to gently rolling and there is good surface and internal drainage.

Maddock Sandy Loam The Maddock series is also classified as a Regosol-Chernozem Intergrade, which developed in loamy sands and sands of glacial origin. The surface soil is noncalcareous light sandy loam, very dark gray, very friable and has a weakly developed fine crumb structure. This grades into a sand and then into a loose, strongly calcareous loamy sand at depths of 4 to 5 feet. The drainage is well to somewhat excessive with rapid permeability and near level topography.

Vienna Loam This includes Chernozem soils developed from glacial till of an older ice sheet than the late Wisconsin. The surface soil is very dark gray, friable, noncalcareous loam of cloddy to moderately developed coarse granular structure. The texture grades into a strongly calcareous clay loam at depths of 18 to 40 inches. It is a well drained soil with moderate permeability developed on nearly level topography. This soil is well adapted for corn and small grain production.

Lamoure Silty Clay Loam The Lamoure series includes calcareous, moderately fine-textured Humic-Gley soils occurring in the bottoms of glacial outwash valleys and on the flood plains of rivers and streams. These soils have a very dark to black, when moist, calcareous A_1 horizon grading into a strongly calcareous gleyed-subsoil horizon of gray, light gray, yellow and olive colors. It is poorly drained and subject to occasional flooding. This soil is nearly level and located on the Sioux River bottom.

Brookings Silt Loam The Brookings soil is moderately well drained developed in slightly weathered calcareous loess over Iowan till. The A horizons are friable when moist and soft to slightly hard when dry. The surface soil is dark to black in color and neutral in reaction. The subsoil is friable, when moist, with lime coming in at depths of 17 to 23 inches. The soils occur on nearly level topography with 0 to 1 percent slope.

Loess Soil An unclassified moderately well drained soil developed in loess over till with nearly level topography. This soil is located in Lincoln County in southeastern South Dakota.

The cropping rotation on the above soils was primarily small grain and corn with very limited uses of legumes, manure and commercial fertilizer.

Experimental Design

The design used in the time of application and crop residue studies was a randomized split plot with four replications. The reason for selecting this type of design was to gain more precision in measuring the expected differences between fall and spring application and likewise, those among the various levels of nitrogen when applied with straw. The design used in the carrier studies was a randomized block type with four replications and nine treatments. Residual information was taken from experiments having both types of designs.

Planting and Harvesting Methods

The field experiments were conducted on private farms in southeastern and east central South Dakota.

The nitrogen carrier used in this study was urea unless otherwise indicated. All solid nitrogen fertilizer was spread by hand and the anhydrous ammonia, when used, was applied with a conventional applicator. A blanket application of phosphorus, as treble superphosphate, was spread on each plot to assure an adequate level of that element. The subsequent tillage and planting operations, completed by the farmer, were the same for the experimental plots as for the fields containing them.

The small grain was harvested by hand and four square yard samples of grain were taken from each plot except for the crop residue studies where 7.36 square yards of sample was taken, using a power harvester. The samples, after being harvested, were dried in a crop dryer set at 105° F., and then threshed. The yields were calculated and recorded in terms of bushels per acre.

The corn was also harvested by hand and where it was checked, ears were taken from all three stalk hills of the center four rows which were surrounded by hills containing two or more stalks. Where the corn was drilled, thirteen rows, ten feet long, were harvested out of each plot. Moisture in the corn at harvest was determined by cutting a center section from 5 to 8 representative ears and drying at 230°F. The pounds of moisture free corn obtained was multiplied by a conversion factor which gave the yield in bushels per acre on a 15.5 percent moisture basis.

Climatological Information

The growing season in 1955 was characterized by below normal rainfall and above normal temperatures. In the Brookings County area, the rainfall was above normal for April and August but below normal for the rest of the year. This fluctuation can be noted in figure 1. The small grain yields in this area were injured by a May drought which was made more acute by high temperatures and strong winds, causing excessive evaporation.

In Lincoln and Turner Counties, the second area of concern in this study, 1955 was characterized by below normal rainfall all during the growing season except June, as shown in figure 2. There was considerable subsoil moisture carried over in this area, but the May drought and high temperatures were so severe that it imposed a ceiling on small grain yields. In regard to corn production, the subsoil moisture and the one inch of above normal rainfall in June were not sufficient to offset the extreme drought that existed during most of the 1955 growing season.

The small grain growing season in the Brookings County area was characterized by near normal rainfall in 1956. However, the slight drought conditions along with high temperatures from June 9 through June 14, seriously affected small grain yields in this area. The above normal rainfall in July, as indicated in figure 1, provided very favorable conditions for corn production.

The extreme drought in Lincoln and Turner Counties during 1956,

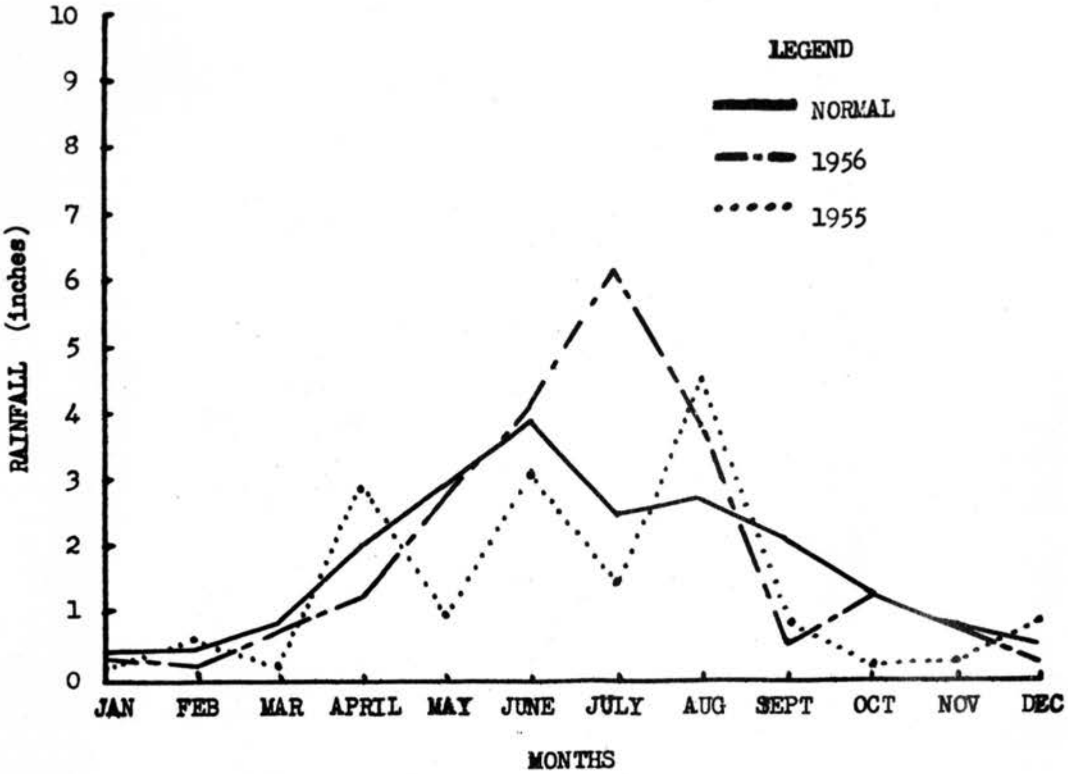


Figure 1. Average annual, 1955 and 1956 precipitation reported for Brookings, South Dakota

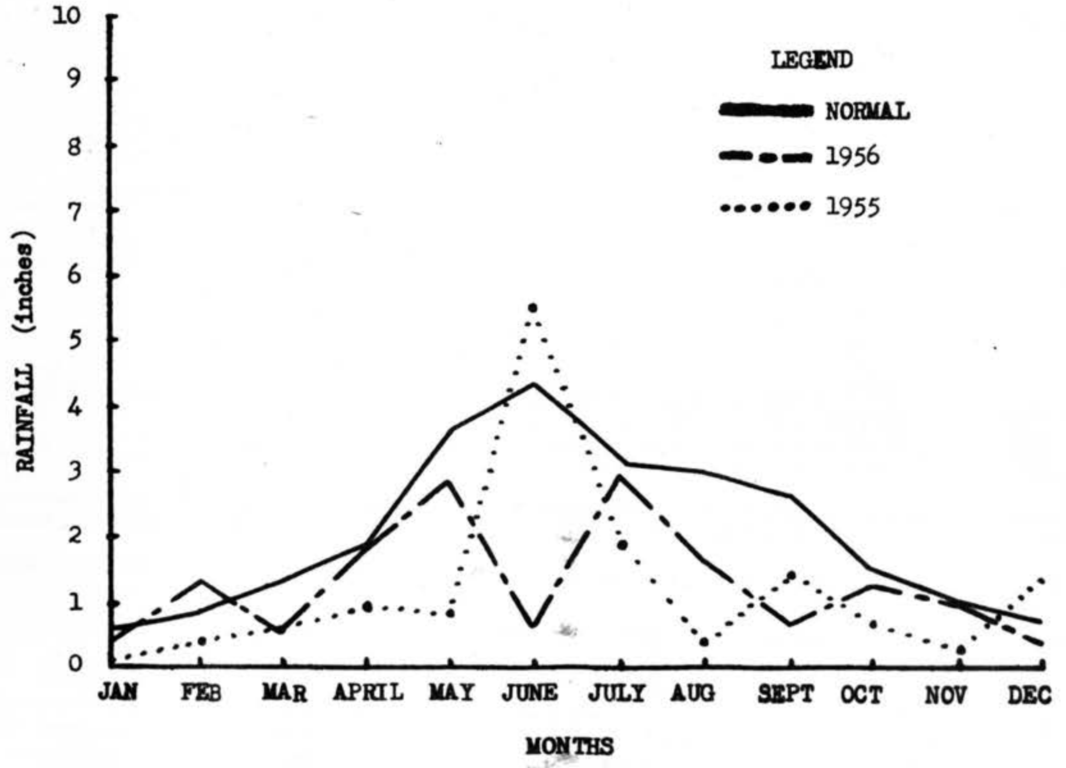


Figure 2. Average annual, 1955 and 1956 precipitation reported for Centerville, South Dakota

had a very serious effect on crop production in that area. There was no subsoil moisture and rainfall for the year was nearly 10 inches below normal. Figure 2 gives a graphic picture of the below normal precipitation through 1956.

EXPERIMENTAL RESULTS

Effect of Fall and Spring Application on Crop Yields

Time of application studies were conducted in Brookings, Deuel, and Lincoln Counties on small grain and corn in 1955 and 1956. The results of these experiments are recorded in Table 1. The data were analyzed statistically and where significance was obtained for fertilizer and time, the least significant differences were recorded. The results of this study are restricted primarily to east central South Dakota due to adverse weather conditions which existed in other areas of the state where experiments were conducted.

The small grain responded significantly to fertilizer with no significant difference between fall and spring application, as shown in figures 3 and 4, on all soils except Maddock sandy loam. On this particular soil, there was no response to fertilizer but there was a significant advantage in favor of spring application. This apparent advantage is believed to be due to the loss of fertilizer by erosion resulting from strong winds the day following the fall application before the fertilizer was disked under. The possibility that this difference between fall and spring application was due to leaching is somewhat remote because the precipitation during the interim of applications was not sufficient to cause any downward movement of the applied nitrogen.

Information obtained from the corn experiment conducted in 1956 on Brookings silt loam is recorded in table 1. The results show that corn yields were not effected significantly by either

Table 1. Effect of Time of Nitrogen Fertilizer Application on Crop Yields.

Treatment pounds / Acre N	P_2O_5	K_2O	Yield Bushels / Acre Fall Application	Spring Application
			Brookings County	
			Wheat - Vienna Loam - 1955	
0	40	0	17.7	18.9
20	40	0	24.8	25.4
40	40	0	31.0	31.6
60	40	0	31.8	35.1
L.S.D. at 5% level				
Fertilizer			2.6	2.6
Time			N.S.	N.S.
			Barley - Maddock Sandy Loam - 1955	
0	40	0	39.8	44.4
20	40	0	44.6	44.9
40	40	0	44.2	49.9
60	40	0	42.1	44.3
L.S.D. at 5% level				
Fertilizer			N.S.	N.S.
Time			3.1	3.1
			Oats - Hecla Loamy Sand - 1956	
0	0	0	30.1	31.7
0	40	0	33.0	33.2
20	40	0	36.4	36.6
40	40	0	41.2	37.9
60	40	0	41.8	33.1
L.S.D. at 5% level				
Fertilizer			6.1	6.1
Time			N.S.	N.S.
			Barley - Kranzburg Silt Loam - 1956	
0	0	0	20.7	19.9
0	40	0	21.4	25.1
20	40	0	29.1	30.0
40	40	0	32.0	37.0
60	40	0	41.0	43.3
L.S.D. at 5% level				
Fertilizer			4.7	4.7
Time			N.S.	N.S.

(continued on next page)

Table 1. Continued

Treatment pounds / Acre			Yield Bushels / Acre	
N	P_2O_5	K_2O	Fall Application	Spring Application
			Deuel County	
			Barley - Kranzburg Silt Loam - 1956	
0	0	0	19.2	22.3
0	40	0	25.1	23.8
20	40	0	30.0	34.5
40	40	0	37.0	39.7
60	40	0	43.4	46.7
L. S. D. at 5% level				
Fertilizer			6.1	6.1
Time			N.S.	N.S.
			Lincoln County	
			Oats - Loess Soil - 1955	
0	60	0	45.8	47.0
40	60	0	50.9	45.6
60	60	0	58.4	58.2
80	60	0	49.3	55.4
L. S. D. at 5% level				
Fertilizer			8.4	8.4
Time			N.S.	N.S.
			Brookings County	
			Corn - Brookings Silt Loam - 1956	
0	0	0	54.8	55.9
0	40	0	60.6	63.4
20	40	0	59.3	55.3
40	40	0	63.8	63.9
60	40	0	66.6	57.1
L. S. D. at 5% level				
Fertilizer			N.S.	N.S.
Time			N.S.	N.S.

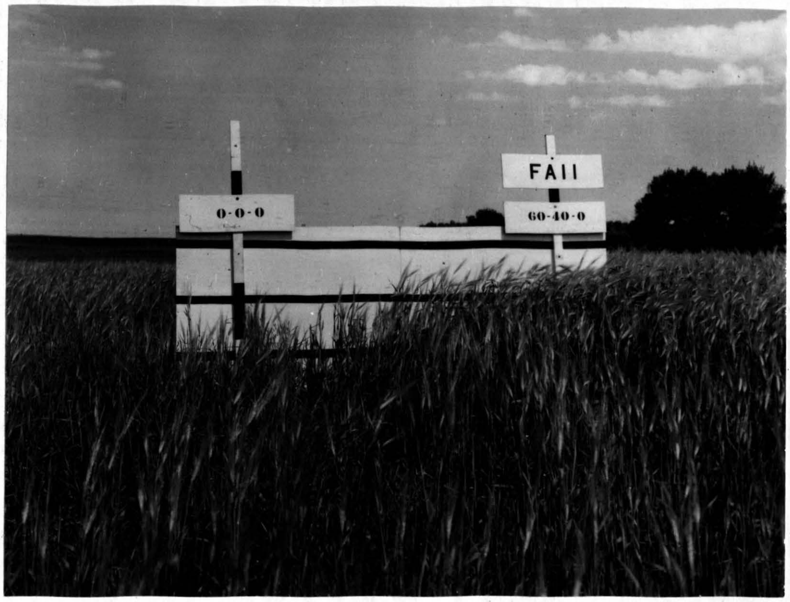


Figure 3. Response of barley to fall applied nitrogen fertilizer.

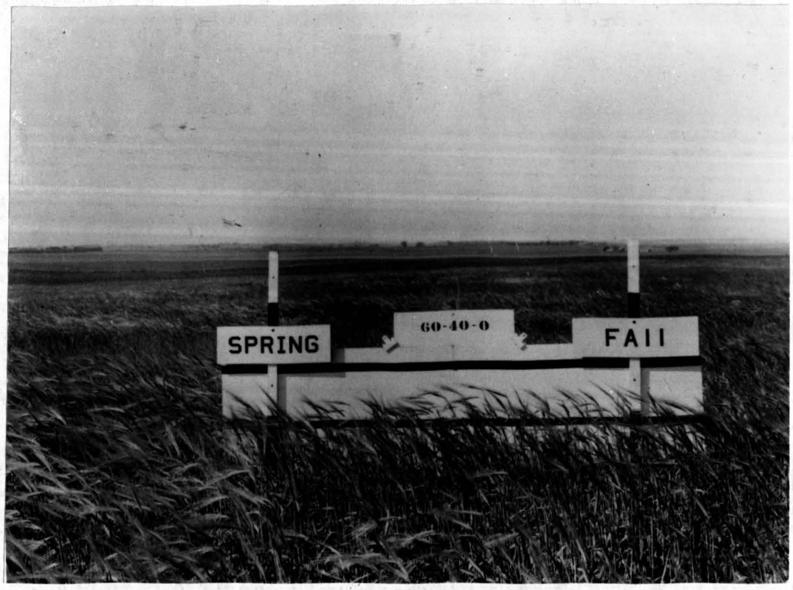


Figure 4. Comparative effect of fall and spring applied nitrogen on barley.

fertilizer or time of application. It was apparent that on this moderately well drained soil where the natural fertility is high and water relationships are favorable, a plant population greater than 10,500 plants per acre may be necessary to make maximum use of the applied fertilizer.

Residual Effect of Nitrogen Fertilizers

Information on residual response of nitrogen was obtained on small grain following corn in two experiments; one in 1955 and one in 1956. The results were analyzed statistically and recorded in tables 2 and 3 along with corn responses to the initial fertilizer applications.

On Lamoure silty clay loam in Brookings County in 1955, oats responded significantly to the carryover from both 40 to 60 pounds of nitrogen. However, it can be noted in table 2 that there was a response to nitrogen only when 40 or 60 pounds of phosphate had been applied on this highly calcareous soil in 1954. The corn yields obtained in 1954 are reported here, along with oat yields in 1955, to give a complete picture of fertilizer utilization over the two year period. Apparently fertilizer had not only increased corn yields significantly the first year, but also increased oat yields 7 to 12 bushels the second year.

In the 1956 experiment on a Kranzburg silt loam in Brookings County, the residual response of barley to nitrogen applied in the fall of 1954 and spring of 1955 was measured. The results shown in table 3 indicate that as little as 40 pounds of nitrogen applied in

Table 2. Residual Effect of Nitrogen Fertilizer on Oats Following Corn in Brookings County, 1955.

Treatment pounds / Acre N	P_2O_5	K_2O	Yield 1954 Corn Bushels / Acre	Yield 1955 Oats Bushels / Acre
			Lamoure Silty Clay Loam	
0	0	0	49.5	40.6
0	40	0	51.1	45.1
40	0	0	48.4	42.9
20	40	0	52.8	47.0
40	40	0	54.1	56.4
60	40	0	58.9	55.9
40	20	0	57.4	45.9
40	60	0	59.9	61.8
0	0	60	48.2	36.2
40	40	40	60.0	45.2
L.S.D. at 5% level				
Fertilizer			5.9	9.1

Table 3. Residual Effect of Nitrogen Fertilizer on Barley Following Corn in Brookings County, 1956.

Treatment pounds / Acre N	P_2O_5	K_2O	Yield 1955 Corn Bushels / Acre Fall	Spring	Yield 1956 Barley Bushels / Acre Fall	Spring
				Kranzburg Silt Loam		
0	60	0	57.5	58.2	24.2	20.6
40	60	0	56.8	59.3	33.2	33.5
60	60	0	54.5	55.9	33.0	40.5
80	60	0	56.9	56.2	37.4	47.8
L.S.D. at 5% level						
Fertilizer			N.S.	N.S.	8.5	8.5
Time			N.S.	N.S.	N.S.	N.S.

Figure 5. Response of barley in 1956 to nitrogen applied in the fall of 1954.

Figure 6. Response of barley in 1956 to nitrogen applied in the spring of 1955.

the fall of 1954, increased barley yields significantly in 1956. This was also true of 60 to 80 pounds of nitrogen applied on the same date. Yield increases due to nitrogen carry-over from the 1955 spring application tended to be higher at the 60 to 80 pound rates than yields produced by carry-over from the previous fall application. However, this difference was not significant at the 5 percent confidence level. The response to residual nitrogen can be noted in figures 5 and 6 and it also can be seen here, by comparison, that very little difference in growth existed between fall and spring application.

Efficiency of Nitrogen Carriers on Corn

Field experiments were conducted in Brookings and Turner Counties comparing the efficiency of three nitrogen carriers: urea, ammonium nitrate and anhydrous ammonia in 1955 and 1956. The yield results were analyzed statistically. The average corn yields, based on 15.5 percent moisture, are recorded in Table 4 along with the least significant difference.

The carrier experiment in 1954 on a well drained till soil (21) was included, with permission, to show that under favorable growing conditions, as there were in Turner County, corn responded equally well to all carriers at all rates of fertilization. The experiment conducted in 1955 in Turner County, on a similar soil, was expected to give information concerning carriers for that area but due to lack of moisture, there was no response to nitrogen fertilizer.

Table 4. Comparative Efficiency of Nitrogen Carriers on Corn

Treatment pounds / Acre N	P_2O_5	K_2O	Source of nitrogen	Yield Bushels / Acre
			Turner County	
			Till Soil - 1954	
0	0	0	None	75.0
40	0	0	Anhydrous Ammonia	83.6
40	0	0	Ammonium Nitrate	79.1
40	40	0	Ammonium Nitrate	83.0
80	0	0	Anhydrous Ammonia	89.2
80	0	0	Ammonium Nitrate	82.8
80	40	0	Anhydrous Ammonia	87.4
80	40	0	Ammonium Nitrate	85.4
80	40	0	Urea	91.8
L.S.D. at 5% level Fertilizer				8.1
			Till Soil - 1955	
0	0	0	None	53.0
40	0	0	Anhydrous Ammonia	56.0
40	0	0	Ammonium Nitrate	56.0
40	40	0	Ammonium Nitrate	59.8
80	0	0	Anhydrous Ammonia	63.4
80	0	0	Ammonium Nitrate	59.9
80	40	0	Anhydrous Ammonia	54.5
80	40	0	Ammonium Nitrate	61.0
80	40	0	Urea	56.8
L.S.D. at 5% level Fertilizer				N.S.
			Brookings County	
			Kranzburg Silt Loam - 1956	
0	0	0	None	55.6
40	0	0	Urea	54.6
40	40	0	Urea	62.2
40	40	0	Ammonium Nitrate	62.8
40	40	0	Anhydrous Ammonia	63.1
80	0	0	Urea	55.6
80	40	0	Urea	67.1
80	40	0	Ammonium Nitrate	65.3
80	40	0	Anhydrous Ammonia	63.6
L.S.D. at 5% level Fertilizer				5.7

Results from the Brookings County experiment in 1956 indicated that all three nitrogen carriers increased corn yields significantly at both the 40 and 60 pound rates. The yields at this location were, however, somewhat reduced by a September 6 frost. It can be noted where phosphate was not applied, the yields were statistically equal to the check regardless of the amount of nitrogen applied. This indicates that a combination of nitrogen and phosphorus was essential for increasing the yields of corn.

Effect of Nitrogen Fertilizer and Straw on Yields of Spring Wheat

An experiment was conducted in Brookings County in 1956 to determine the interrelation between levels of nitrogen fertilizer and levels of straw application on the yield of wheat. Plot preparation was accomplished by weighing out the required amount of baled oat straw, spreading it evenly over the plot and plowing it under with a mold-board plow. On plots requiring an equivalent of 5 and 10 tons per acre, it was necessary to rake a portion of the straw into the plow furrow to facilitate covering. This sequential operation of plowing under straw is shown in figures 7, 8, and 9.

The wheat yields are recorded in table 5 along with the least significant difference for straw and nitrogen. A statistical analysis of the yield indicates that straw depressed yields significantly at every level of nitrogen. This yield depression, which can be noted in table 5, varied from a significant 3.1 bushels at the 1.25 ton rate to 4.5 bushels at the 10 ton level. When the effect of straw levels is broken down into individual degrees of freedom, as

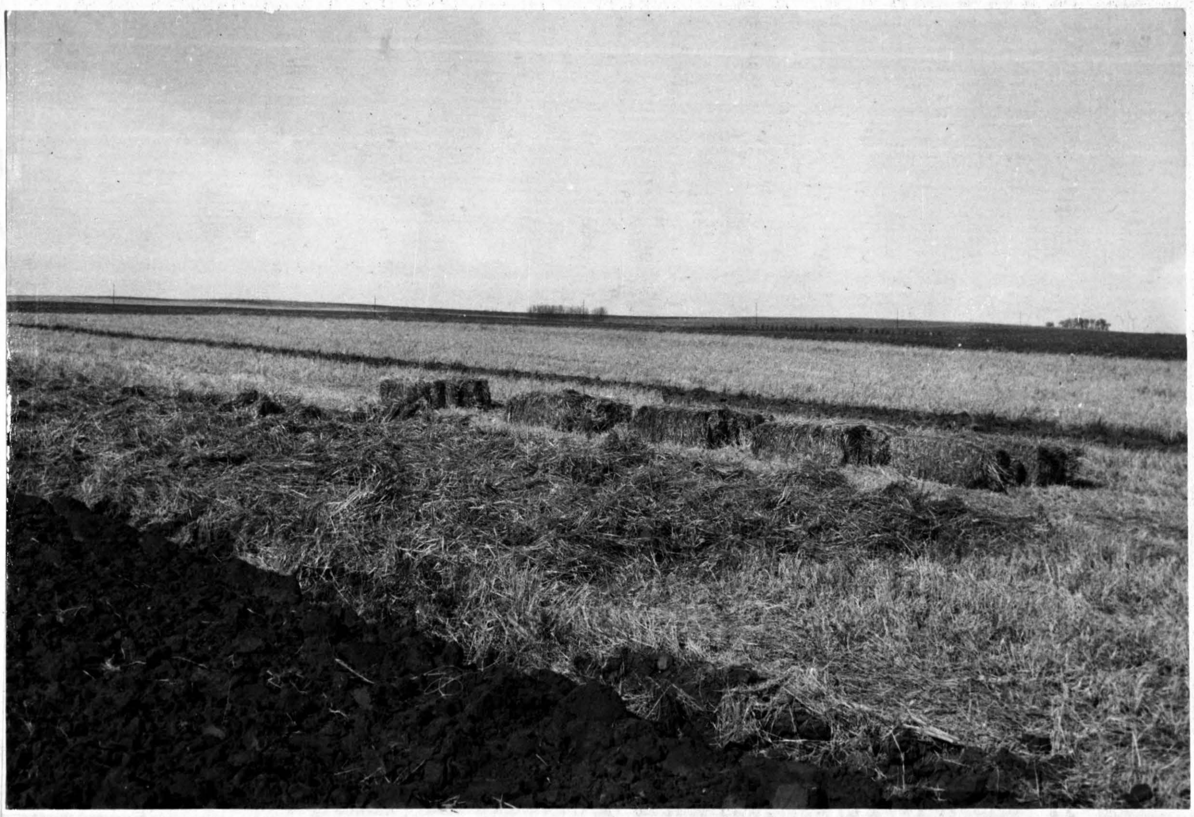


Figure 7. Application of 10 tons of straw per acre before and after spreading.

Figure 8. Raking straw into plow furrow to facilitate covering.

Figure 9. Straw being covered with a moldboard plow.

Table 5. Influence of Straw and Nitrogen on the Yield of Spring Wheat in Brookings County, 1956.

Tons of Straw Applied / Acre	Pounds of Nitrogen Applied / Acre 0	12.5	25.0	50.0	100.0	Average for Straw Levels
	Bu/A.	Bu/A.	Bu/A.	Bu/A.	Bu/A.	Bu/A
0	12.3	14.2	18.2	20.5	22.8	17.6
1.25	8.7	11.0	14.9	17.6	20.4	14.5
2.50	9.4	10.0	17.0	17.1	19.8	14.7
5.00	6.9	9.3	11.4	15.4	19.6	12.5
10.00	8.0	12.0	13.8	14.7	17.0	13.1
Average for Nitrogen Levels	9.1	11.3	15.1	17.1	20.0	

L.S.D. at 5% level for straw over all levels of nitrogen - 2.5
L.S.D. at 5% level for nitrogen over all levels of straw - 1.4

Table 6. Analysis of Variance of Wheat Yields Reported in Table 5.

Source of Variation	d.f.	Mean square
Replications	3	70.3*
Straw	4	77.7**
No straw vs. straw	1	236.2**
Low levels vs. high levels	1	70.1*
1.25 tons vs. 2.5 tons	1	1.2
5 tons vs. 10 tons	1	3.2
Error a	12	13.4
Nitrogen	4	272.8**
No nitrogen vs. nitrogen	1	741.6**
Low levels vs. high levels	1	542.1**
12.5 pounds vs. 25 pounds	1	126.8**
50 pounds vs. 100 pounds	1	80.5**
Nitrogen x straw	16	4.5
Error b	60	4.7
Total	99	

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

seen in table 6, it can be shown that high levels of straw (5 and 10 tons) reduced yields significantly when compared with the mean yields obtained from lower levels of straw (1.25 and 2.5 tons). However, there is no statistical difference between the effects of 1.25 and 2.5 tons of straw on yield and likewise, no difference between 5 and 10 tons of straw applied per acre.

In the analysis of subplot effects, the variation due to nitrogen was highly significant. It can be noted in table 5 that an application of as little as 12.5 pounds of nitrogen per acre produced an average significant yield increase of 2.2 bushels over all levels of straw. Upon testing the single degrees of freedom for nitrogen levels, it was also noted that 25 pounds of nitrogen produced highly significant yield increases over 12.5 pounds. A highly significant difference in yield was also found when the response to 50 pounds of nitrogen was compared with that of 100 pounds. The comparative effects of no nitrogen and 100 pounds at all straw levels are shown in Figures 10, 11, 12, 13, and 14. The detailed study of the effect of nitrogen indicates that as nitrogen was increased there was a continuous increase in the yield of wheat over all levels of straw. A more complete analysis of this linear response is shown in table 7. The sum of squares from the linear component has taken up essentially all total sum of squares and was highly significant within all levels of straw. Significance was obtained for the quadratic component at the 5 ton level, however, the additional sum of squares obtained over and above that for the linear response was comparatively small, indicating the response was

Figure 10. Effect of 100 pounds of nitrogen on yield of spring wheat when no straw had been applied.

Figure 11. Effect of 100 pounds of nitrogen on the yield of spring wheat when 1.25 tons of straw per acre had been applied.

Figure 12. Effect of 100 pounds of nitrogen on the yield of spring wheat when 2.5 tons of straw per acre had been applied.

Figure 13. Effect of 100 pounds of nitrogen on the yield of spring wheat when 5 tons of straw per acre had been applied.

Figure 14. Effect of 100 pounds of nitrogen on yield of the spring wheat when 10 tons of straw per acre had been applied.

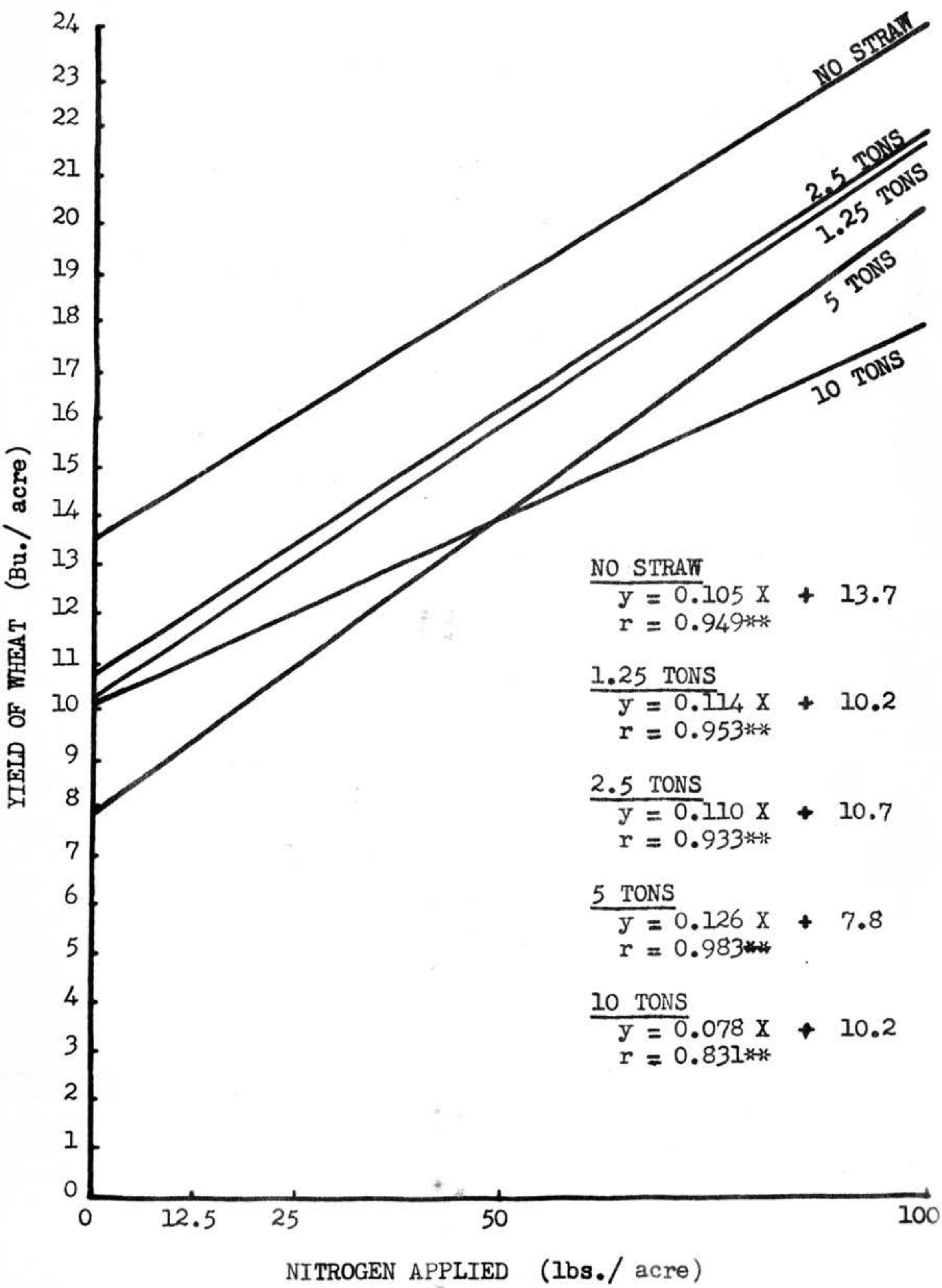
Table 7. Separation of Nitrogen Effects Within Each Straw Level into Linear, Quadratic, Cubic, and Quartic Components.

Component	D.F.	Straw Levels				
		No Straw	1.25 Tons	2.5 Tons	5 Tons	10 Tons
		M.S.	M.S.	M.S.	M.S.	M.S.
Linear	1	299.1**	355.9**	289.4**	398.4**	168.4**
Quadratic	1	0.2	0.0	4.0	9.2*	5.3
Cubic	1	2.0	0.9	1.7	0.1	5.4
Quartic	1	1.8	0.4	19.1	0.9	0.1
Interaction	12	6.7	6.5	5.7	1.6	3.2

* Significant at 5% confidence level
** Significant at 1% confidence level

primarily linear. This is to be expected because there was a continuous rise in wheat yields with increased nitrogen. The linearity of response indicates the point of diminishing returns was not reached with respect to nitrogen fertilizer, regardless of the amount of straw applied. The analysis of linear regression of yield on nitrogen for the five levels of straw is shown in figure 15 along with the highly significant correlation coefficient.

All regression lines are nearly parallel except at the ten ton level. This indicates that each increment of added fertilizer produced nearly the same corresponding yield increase under all levels of straw as where no straw was applied. The exception to this is the 10 ton level where a smaller yield increase was realized from each nitrogen addition. This could be expected because at such a high rate of straw application soil organisms immobilize most of the available nitrogen in the decomposition process. It is interesting to note in figure 15 that the regression lines of 1.25 and 2.5 tons of straw nearly coincide which means there was very



** Significant at 1% level

Figure 15. Regression of yield of wheat on nitrogen at all levels of straw.

little difference between the effect of 1.25 and 2.5 tons of straw on the yield of wheat. This point was also brought out in table 6 when a statistical comparison between these two rates proved to be non-significant.

DISCUSSION

Continuous crop production in much of South Dakota has resulted in the depletion of soil nitrogen. This has made it necessary to use an increased amount of fertilizer and other soil fertility practices in order to maintain crop yields at a profitable level. The effect of long time cropping on South Dakota soils has been to reduce the total nitrogen content and the organic matter of the soil up to 50 percent (20). The problem of maintaining soil productivity appears to fall into two categories: maintaining plant nutrient levels and soil organic matter. The former may be satisfied by adding commercial fertilizer and the latter involves soil management practices, including the application of green manure and crop residues.

The results reported here, which have reference to maintaining soil productivity through the use of commercial fertilizer, are concerned primarily with time of application and the residual effects of nitrogen. The data obtained, under the existing conditions of this study, indicate that fall application for small grain was equally as effective for increasing crop yields as spring application. This means that fertilizer can be applied in the fall when time is not a premium as it often is in the spring. Further implications are that better and more complete custom services will be available in the fall as well as a better selection of fertilizer materials. There is a possibility that dealers may offer a monetary incentive for fall application because it will lengthen their productive season and reduce overwinter storage costs. There are some possible disadvantages to fall application, such as, the tying up of farm capital that may be needed during the winter months and not providing the opportunity to evaluate crop prospects as can be done to a limited extent in the spring. The latter factor is perhaps not too important because the information obtained concerning residual effects, indicates that if fall applied nitrogen is not utilized one year, it may be carried over for use the following year. This provides assurance that if a crop fails as a result of drought conditions, the fertilizer will not be lost and part of the monetary investment in the fertilizer will be recovered. Results of this study have shown that fall and spring applied nitrogen to corn, which did not respond as a result of drought, significantly increased barley yields the following year. There was further evidence to show that nitrogen applied in the spring not only increased corn yields significantly, but also increased oat yields as much as 12 bushels per acre the year following corn. This is in agreement with the findings of Pesek and Dumenil in Iowa (18).

The second aspect of this study was concerned with the problem of how much nitrogen will be required to prevent yield reductions when various amounts of straw have been plowed under. This problem arises from the fact that when moderate amounts of straw are incorporated into the soil, most of the available soil nitrogen is immobilized by soil organisms and consequently, crops do not have sufficient nitrogen to make maximum growth (14). This seems to indicate that a farmer who utilizes crop residues in his soil management program would be penalized for doing so by taking a reduction in yield. In view of this situation, the tendency has been to remove excess crop residues by burning in order to avoid reduced yields. This practice has resulted in a continuous decline in organic matter and nitrogen content of the soil. The evidence obtained under the conditions of this experiment indicates that if as little as 12.5 pounds of nitrogen were plowed under with straw, including rates as high as 10 tons per acre, a significant yield increase, would be realized. This average yield, over all levels of straw, was not as high as the check, but it did show that this small amount of nitrogen made a significant contribution toward removing the harmful effects of straw. An application of no more than 25 pounds of nitrogen per acre did increase yields, over all levels of straw, to 15.1 bushels per acre as compared to 12.3 bushels for the check. This indicates that an application of 25 pounds of nitrogen per acre fulfilled the requirements of soil organisms and produced a slight yield increase over plots that received no nitrogen or straw. The experimental evidence obtained under the conditions of this investigation, indicates that if a small amount of nitrogen (25 pounds per acre) were plowed under with the crop residues, the depressing effect of straw on yields might be eliminated. Furthermore a slight yield increase may also be realized as well as improving the organic matter and nitrogen content of the soil.

SUMMARY AND CONCLUSIONS

Fertilizer experiments were conducted in southeastern and east central South Dakota on small grain and corn to investigate factors affecting efficient use of nitrogen fertilizers. The factors of concern here were time of application, nitrogen carry-over, efficiency of nitrogen carriers and the interrelation between nitrogen and rates of straw application on small grain yields. The results obtained, under the conditions which existed during this study, are as follows:

1. There was no apparent difference between the effect of fall and spring applied nitrogen on yields of small grain.

2. Special care should be taken to make sure fertilizer applied in the fall on bare, sandy soil is adequately covered in order to prevent loss of nitrogen due to wind erosion.

3. The experimental evidence regarding time of application for corn production was insufficient to justify any conclusions.

4. The carry-over effect of fertilizer applied to corn significantly increased the yield of the succeeding oats crop as much as 12 bushels per acre on Lamoure silty clay loam. The residual effect of 40 pounds of nitrogen per acre applied on corn in the fall of 1954 and/or spring of 1955, was sufficient to increase barley yields significantly in 1956 on Kranzburg silt loam.

5. Corn responded equally well to urea, anhydrous ammonia, and ammonium nitrate at both the 40 and 60 pound rates of application.

6. All rates of straw application depressed the yields of

wheat over all levels of nitrogen from 12.5 pounds to 100 pounds per acre.

7. There was no significant difference between the effects of 1.25 and 2.5 tons of straw on yield and likewise, no difference between 5 and 10 tons of straw applied per acre.

8. An application of as little as 12.5 pounds of nitrogen per acre produced a significant increase in the yield of wheat over all levels of straw.

9. It was further noted that each additional increment of nitrogen fertilizer (25, 50 and 100 pounds) produced significant yield increases over and above that of the preceeding rate of application.

10. The parallelism of the regression lines indicates that nitrogen fertilizer was used with about the same efficiency over all levels of straw except at the 10 ton level. At this particular level, a smaller yield increase was realized from each nitrogen addition because most of the available nitrogen was immobilized by soil organisms during the decomposition process.

LITERATURE CITED

1. Albrecht, W. A. Nitrate Accumulation Under Straw Mulch. Soil Sci. 20:253-256. 1922.

2. Andrews, W. B., Edwards, F. E. and Hammons, J. G. Ammonia as a Source of Nitrogen. Miss. Agr. Exp. Sta. Bul. 448. 1947.

3. Blair A. W. and Prince, A. L. The Influence of Heavy Applications of Dry Organic Matter on Crop Yields and on Nitrate Content of the Soil. Soil Sci. 25:281-289. 1928.

4. Brage, B. L. Spring or Fall Application of Fertilizer? S. Dak. Farm and Home Research. Vol. VI, No. 3. Spring 1955. pp. 62-65, 74-76.

5. Brown, P. E. and Allison, F. E. The Influence of Some Common Humus-forming Materials of Narrow and Wide Nitrogen - Carbon Ratios on Bacterial Activities. Soil Sci. 1:45-75. 1916.

6. Collison, R. C. and Conn, H. J. The Effect of Straw on Plant Growth. N. Y. Agr. Sta. Tech. Bul. 114. 1925.

7. Doryland, C. J. T. The Influence of Energy Material Upon the Relation of Soil Micro-organism to Soluble Plant Food. N. Dak. Agr. Exp. Sta. Bul. 116. 1916.

8. Hammons, J. G. The Efficiency of Anhydrous Ammonia as a Source of Nitrogen on Fall-planted Oats for Forage and Grain Production. Soil Sci. Soc. Amer. Proc. Vol. 12:266-269. 1948.

9. Hutchinson, H. B. The Influence of Sugar and Plant Residues on Losses of Soil Nitrate. Jour. Agr. Sci. 9:92-111. 1919.

10. Larsen, J. E. and Kohnke, H. Relative Merits of Fall and Spring Applied Nitrogen Fertilizer. Soil Sci. Soc. Amer. Proc. 11:378-383. 1942.

11. Lyon, T. L., Bizzell, J. A. and Wilson, B. D. Depressive Influence of Certain Higher Plants on the Accumulation of Nitrates in the Soil. Jour. Amer. Soc. Agron. 15:457-466. 1923.

12. MacGregor, J. M. The Effect of Time and Placement of Fertilizer for Corn. Report of Joint Meetings of Agronomists with the Fertilizer Industry sponsored by the Middle West Soil Improvement Committee. Feb. 17 and 18, 1955. pp. 18-26.

13. Martin, T. L. Effect of Straw on Accumulation of Nitrates and Crop Growth. Soil Sci. 20:159-164. 1925.

14. Murray, T. J. The Effect of Straw on Biological Soil Processes. Soil Sci. 12:233-259. 1921.

15. Nelson, L. B. and Uhland, R. E. Factors that Influence Loss of Fall Applied Fertilizer and their Probably Importance in Different Sections of the United States. Soil Sci. Soc. Amer. Proc. 19:492-496. 1955.

16. Paschal, J. L. and French, B. L. A Method of Economic Analysis Applied to Nitrogen Fertilizer Rate Experiments on Irrigated Corn. U. S. Dept. Agr. Tech. Bul. No. 1141. May, 1956.

17. Pesek, J. Time of Application of Fertilizer. Report of Joint Meetings of Agronomists with the Fertilizer Industry sponsored by the Middle West Soil Improvement Committee. Feb. 20, 1953.

18. ______ and Dumenil, L. How Much Fertilizer Carry Over? Crops and Soils. June-July, 1955; pp. 24-25.

19. Pinck, L. A., Allison, F. E. and Gaddy, V. A. The Nitrogen Requirements in the Utilization of Carbonaceous Residues in Soi. Jour. Amer. Soc. Agron. 38:410-420. 1946.

20. Puhr, L. F., and Olsen, O. A Preliminary Study of the Effect of Cultivation on Certain Chemical and Physical Properties of Some South Dakota Soils. S. Dak. Agr. Exp. Sta. Bul. 314. 1937.

21. ______, Shubeck, F. E., Brage, B. L., Fine, L. O., and Carson, P. L. South Dakota Fertilizer Experiments, 1954. S. Dak. Exp. Sta. Pam. 29. 1954.

22. Rhoades, H. F., Howe, O. W., Bandurant, J. A. and Hamilton, F. B. Fertilizer and Irrigation Practices for Corn Production on Newly Irrigated Land in the Republican Valley. Nebr. Agr. Exp. Sta. Bul. 424. 1954.

23. Scott, H. The Influence of Wheat Straw on the Accumulation of Nitrates in the Soil. Jour. Amer. Soc. Agron. 13:233-258. 1921.

24. Smith, F. W. Kansas Fertilizer Studies - 1949. Report of Joint Meetings of Agronomists with the Fertilizer Industry sponsored by the Middle West Soil Improvement Committee. Feb. 24, 1950.

25. Standford, G. Recent Fertilizer Experiments in Iowa. Report of Joint Meetings of Agronomists with the Fertilizer Industry sponsored by the Middle West Soil Improvement Committee. Feb. 24, 1950.

26. Thomas, R. P. and Harper, H. J. The Use of Oat Straw in a System of Soil Fertility. Soil Sci. 21:393-400. 1926.

27. Viets, F. G., Nelsen, C. E. and Crawford, C. L. The Relationship Among Corn Yields, Leaf Composition and Fertilizer Applied. Soil Sci. Soc. Amer. Proc. 18:277-301. 1954.

28. Waksman, S. A. Influence of Micro-organisms upon the Carbon-Nitrogen Ratio in the Soil. Jour. Agr. Sci. 14:555-562. 1924.

29. ______ and Tenney, F. G. The Composition of Natural Organic Materials and Their Decomposition in the Soil II. Influence of Age of Plant Upon the Rapidity and Nature of its Decomposition--Rye Plants. Soil Sci. 24:317-333. 1927.

30. Westin, F. C., Buntley, G. J. and Brage, B. L. Soil and Weather. Cir. 116. May 1955. pp. 12.