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Effect of Time of Fertilizer Application on Yield and Quality of Oats and Barley

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EFFECT OF TIME OF FERTILIZER APPLICATION ON YIELD AND QUALITY OF OATS AND BARLEY

BY

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EFFECT OF TIME OF FERTILIZER APPLICATION

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AND BARLEY

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.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The soils of eastern South Dakota have lost much of their original productivity through cropping, erosion and cultivation. It has been estimated that 25 to 40 percent of the original nitrogen content and 40 to 50 percent of the original organic matter has been lost. From 10 to 15 percent of the nitrogen which is annually utilized by crops is replaced through the current soil management practices.

The use of fertilizer has become an essential part of good soil management. Most South Dakota soils have the capacity to supply all of the essential elements required for crop production except nitrogen and phosphorus. These two elements are required in large amounts by most crops and maximum crop yields can not be expected unless these two elements exist in available form in large quantities in the soil.

About 50 percent of the cropland in eastern South Dakota is planted to small grains each year. Much of the small grain crop follows corn in the crop rotation, especially in the counties near the eastern border of the state. Since corn requires large amounts of nitrogen, the supply of nitrates in the soil following corn is generally low. The soil nitrogen problem is further aggravated by the return of highly carbonaceous cornstalk residues which immobilize nitrogen in the process of humification. Nitrification under small grain is also less than under corn. Current estimates are that nitrification under small grain in South Dakota is about one percent of the total soil nitrogen per year while nitrification under corn is about two percent per year. The process of nitrification is also slow in the early growing season, because of low soil temperatures.

For these reasons, many small grain fields show nitrogen deficiency symptoms in May and June.

The level of soil moisture at the time of small grain planting is very often low and many farmers are hesitant to invest in fertilizer for small grain. In May, when the moisture outlook generally improves and when nitrogen deficiency symptoms have appeared in the small grain, farmers are interested in knowing if the application of fertilizer will still give a profitable response.

The main objective of this study was to determine the effect of the time of application of fertilizer on the yield of small grain and also on the quality as measured by the protein content. A supplementary objective was to compare the effect of two rates of nitrogen, applied with and without phosphorus, to the grain at three different times. Another supplementary objective was the comparative effect of two carriers of nitrogen applied on the small grain at various dates.

REVIEW OF LITERATURE

Status of Soil Fertility in Eastern South Dakota

The soils of eastern South Dakota, for the most part, lie in the Chernozem Great Soil group. These soils developed in an environment of limited rainfall and are characterized by a horizon of calcium carbonate accumulation in the soil profile. In the virgin condition, these soils were very fertile. Through intensive cultivation, crop removal, erosion, and other causes, the loss of soil nutrients has been great enough to cause nitrogen and phosphorus deficiencies to appear in many soils in 60 to 80 years of cultivation.

In studies on the effects of cultivation on soils, Puhr and Olson (22) found that an average of 29 percent of the nitrogen and 42 percent of the organic matter originally contained in the virgin soil had been lost since it was brought under cultivation. They concluded that the crop rotations commonly practiced did not generally include legumes to restore the nitrogen and organic matter lost through cultivation. Puhr and Worzella (23) reported that eastern South Dakota soils have lost an average of 35 percent of the total nitrogen and 40 percent of the total organic matter in 65 years of farming.

Puhr and Worzella (23) found that the total phosphorus content in most South Dakota soils was high, but the phosphorus removal by crops was greater than the rate of replenishment of available phosphorus from the total supply. Consequently, the available phosphorus content has diminished to the point where the growing crop can not receive enough phosphorus from the soil. Puhr and Olson (22) found that the total phosphorus content has decreased 13.1 percent since the land was brought under cultivation.

The soils of eastern South Dakota have the capacity, at the present time, to supply sufficient available potassium for general crop production. Plants require large amounts of potassium, but much of this is returned to the soil in the form of crop residues and manure.

Effect of Fertilizer on the Yield and Protein Content of Small Grains

The rate of release of available nitrogen from the total nitrogen supply in the soil is less for small grain than for corn. Corn is usually planted later in the growing season when the soil is warmer and nitrification makes more nitrogen available to plants. The process of cultivation aerates the soil which in turn accelerates nitrification. Soil management practices such as growing legumes or applying manure or commercial fertilizer are usually pointed towards giving the greatest benefit towards the corn crop. Small grains are planted earlier in the spring when little nitrification is occurring and nitrogen deficiency symptoms are prevalent in many small grain fields every spring.

On most soils the application of nitrogen increases the yield of small grain. Brieba (3), Carson (5), Nelson et al. (16), Olson and Dreier (18), Pritchett (21), and Puhr et al. (24) reported that the yield of oats was increased due to the addition of nitrogen in almost every experiment. Davidson (7) and Gericke (9) reported that the yield of wheat also increased with the application of nitrogen.

Many experiments have been conducted concerning the rates of nitrogen to be applied to small grain. Bartholomew (2) in Arkansas, Carson (5), Nelson et al. (17) and Pendleton (19) in Iowa, Puhr et al. (24) in South Dakota, and Robertson et al. (25) in Michigan reported that the first 20 pounds of applied nitrogen caused the largest per pound increase in yield. One bushel of oats contains about one pound of nitrogen. Nelson et al., (16) found that the yield of oats was increased about 10 bushels per acre when 20 pounds of nitrogen was applied per acre. More nitrogen was required per bushel increase with higher rates of application. Macy (15) stated "The sufficiency of a nutrient is a function of its percentage content in the plants." In an experiment with oats, he defined luxury consumption as the point where there was more available nitrogen than was needed for the amount of grain produced, so the nitrogen not utilized for grain production was used to increase the nitrogen content of the plant.

The previous cropping history greatly influences the crop response to nitrogen. Nelson et al. (17) found that those crops two or more years from a legume produced twice the increase in yield from applied nitrogen compared to those separated by only one year from a legume. The efficiency of nitrogen recovery was increased when the oats followed two or more years of corn.

If the amount of available phosphorus or potassium is inadequate, the efficiency of nitrogen is also reduced. Pingree (20) found that if phosphorus and potassium were the limiting nutrients, more nitrogen would be taken up per pound of dry matter, but the total amount of dry matter as well as the yield would also be smaller than when a complete fertilizer was used. Kraybill (16) found that if phosphorus and/or potassium are deficient in the soil, the inclusion of these elements with the applied nitrogen increased the amount of carbonaceous material produced more than did the application of only nitrogen. The yield of grain was also greater than that produced by nitrogen alone.

Nitrogen generally increases the protein content of small grains. In a greenhouse experiment with wheat, Gericke (9) was able to show that variations in the protein content of grain are not always due to genetic factors but can be the response of the plant to its environment. Davidson (7) stated that the amount of increase depends upon the amount of nitrogen available to the plant at heading time. Gericke (11) concluded in part, "that supply of nitrogen available for the quantity of grain that any state of vegetative development may induce, determines the protein content of any sample of wheat."

Thatcher and Arny (26) found that previous cropping history influenced the percent protein. Those grains grown in oats, wheat, and corn rotations were low in protein and those grown in a longer rotation including a legume had a higher protein content. This increase was probably due to the extra nitrogen which had been fixed in the soil by the legumes. In an experiment conducted on the above rotations, when potassium was added to manure which was applied to the soil, the protein content of the grain was lower than where no manure was applied. When phosphorus was included with manure, the protein content was the same as the check. There were no yields given for the grain in the experiment so it is possible that the plots which were treated with manure, reinforced with phosphorus or potassium, produced a higher yield than those which received no manure. If this was true, the nitrogen in the manure was utilized in the increased yield and there probably was not enough to increase the protein content. Kraybill (14) also reasoned that the protein content of grains was decreased when phosphorus and potassium were added because the increase in vegetative growth left less nitrogen available for the development of the grain kernel.

Effect of Time of Application on Yield and Protein Content

The time of the application of the nitrogen may affect the yield of small grain. Kraybill (14) and Davidson (7) found that the application of nitrogen in the early phases of the plant's growth cycle will tend to increase the degree of vegetative development. This will offer increased opportunity for the synthesis of carbohydrates and may produce a larger number of heads due to tillering and may result in conditions favoring a greater yield of wheat. This reasoning would hold true for all of the small grains. Pendleton (19) reported that in both greenhouse and field experiments, the early application was more effective in producing an increase in yield than were the late applications. The late applications were seven and nine weeks after the oats was planted. Burd (4), in a study on the absorption of soil constituents by barley, found that this absorption was divided into three distinct phases. The first phase was a period of progressively increasing rate of absorption ending at heading. At this stage the nitrogen and phosphorus content were the same as they were at maturity, and the potassium content was actually greater than at maturity. In the second phase, there was an actual loss of nutrients to the surrounding medium and migration into the kernel. In the third phase, at ripening, the absorption ceases. Hoagland (12), working with barley in sand cultures, found that the addition of plant nutrients did not affect the yield after the first eight to ten weeks. Gericke (10) placed sodium nitrate on oats at the rate of 82 pounds per acre at seven different intervals in a pot experiment using Oakley sand which is very deficient in nitrogen. He reported a progressive yield increase until 90 days after planting and then a marked decline in yield occurred. He also compared sodium nitrate with ammonium sulfate on oats, rye, spring wheat and winter wheat and noted consistent differences in the magnitude of response to the two carriers. Those pots which were treated with ammonium sulfate at the earlier dates produced a higher yield than did those treated with sodium nitrate. The reason given for this difference was that some time was required for the nitrogen in the ammonium sulfate to nitrify and become available as nitrate. An application of nitrogen as ammonium sulfate at planting should, therefore, be expected to produce a larger yield than an equal application of nitrogen in the form of sodium nitrate because the nitrogen in the ammonium sulfate becomes available at a later stage of growth when the plant can utilize the nitrogen more efficiently.

Appleton and Helms (1) checked the rate of nitrate absorption by plants and found that the rate of absorption was more rapid when the nitrogen was applied at comparatively late stages of growth. They concluded that at first the stage of plant development limited the rate of nitrogen absorption. As the root system was developed, the growth of the plant was limited by the supply of available nitrogen. They obtained similar results with cotton and oats. When the nitrogen was applied 14 days after planting, it took 48 days to absorb all of the applied nitrogen and when the nitrogen was applied 92 days after planting, it took only 10 days to absorb all of the nitrogen. The rate of absorption and the rate of growth were closely correlated.

Robertson et al. (25), conversely, reported a greater yield increase on oats by top dressing six weeks after planting than when the fertilizer was plowed down. Some of the nitrogen which was plowed down was probably immobilized by the decaying organic matter and therefore was not immediately available, whereas that which was topdressed was available to the plant as soon as it reached the root zone. Bartholomew (2) applied nitrogen to oats at various stages of plant growth from planting until the grain was six inches tall and found no difference due to dates. Brieba (3) applied 80 pounds of nitrogen per acre to oats at five dates and found the greatest yield resulted when the nitrogen was applied one week after emergence and then a progressive decline occurred until the application seven weeks after emergence, when a sharp decline resulted. Davidson and LeClerc (8) attempted to determine if the effectiveness of nitrogen on the yield disappears sharply or gradually by delaying application when the plant was still in the vegetative stage. They found that by delaying application of nitrogen on red winter wheat from the resumption of growth in the spring until just before heading, the yield gradually decreased.

Davidson and LeClerc (8) also found that the protein content of the grain gradually increased as the time of application was delayed. They applied nitrate of soda at the rate of 320 pounds per acre when the plants were two inches in height, at heading, and when the plants were in the "milk" stage. They found that the application of nitrogen at the earliest stage of growth produced the highest yields and application at the time of heading produced the highest protein content. When the nitrogen was applied at the "milk" stage, however, it had no effect on the yield or protein content. Kraybill (14) stated that "applications of nitrogen close to the heading time should increase the amount of nitrogenous materials in proportion to the available carbohydrates and result in higher protein wheats." Davidson (7), Macy (15), and Pendleton (19) also noted an increase in the protein content of the grain as the application of nitrogen was delayed. In a greenhouse experiment, Gericke (9) found that the protein content of oats increased from 7.5 percent to 17.2 percent when the application of nitrogen was delayed from planting to 108 days after planting.

Other Effects of Fertilization of Small Grain

The maturity of small grain may also be affected by applying fertilizer. In a greenhouse experiment, Gericke (9) noted that the maturity of oats was delayed from 197 to 219 days when nitrogen was applied 108 days after planting. Brieba (3), however, found that the time of application of nitrogen had no effect on maturity unless high rates of nitrogen were used. The key to the effect of optimum amounts of added nitrogen on maturity probably lies in the amount of phosphorus available to the plant. If there is an adequate amount of available phosphorus, then the addition of moderate amounts of nitrogen will not delay maturity. Pendleton (19) stated that 200 pounds of sodium nitrate delayed maturity, but phosphorus may have been the limiting factor in the experiment. A late growth of straw occurred which may have induced a deficiency of one or more nutrients that resulted in delaying the maturity of oats. Burd (4) stated that late applications of nitrogen may delay maturity because large concentrations of nitrogen may bring about an unfavorable relationship in the plant at the later stages of growth which may slow the maturation process.

The effect of nitrogen on lodging of small grain has also been investigated. Robertson et al. (25) found no lodging occurring when rates of nitrogen up to 80 pounds per acre were used. Nelson et al. (16) stated that with high rates of nitrogen, lodging depends largely upon the variety. At the 20 pound rate, there was no lodging, even in varieties not outstanding for lodging resistance.

Casserly (6) used culm diameter, root type, and plant height to measure lodging resistance in oats. He found that when phosphorus is applied alone or in combination with nitrogen or nitrogen and potassium, the lodging resistance was increased. When nitrogen was applied alone, it gave a decrease in lodging resistance as compared with the check plants. If a soil is low in phosphorus, an application of nitrogen may therefore increase lodging if a high rate was used and the variety was not too resistant to lodging.

METHODS AND PROCEDURE

Field Experiments

Twelve field experiments were conducted on private farms located in the two eastern tiers of counties in South Dakota in 1958 and again in 1959. The general locations of all the experiments are shown on the accompanying map, Figure 1.

Composite soil samples were taken from each experimental site. These samples were analyzed for available phosphorus and potassium and also total nitrogen. This was done to better estimate the relative ability of the soil to supply these nutrients to the crop.

The experimental design used in the 1958 experiments was a randomized split plot with four replications. The dimensions of each individual plot were 12 feet by 20 feet. The reason for selecting this type of design was to gain more precision in measuring any differences due to the time of application and therefore less emphasis was placed upon the rates of nitrogen.

The treatments used were check, N_1, N_1P, N_2, and N_2P; where N_1 and N_2 were 20 and 40 pounds of nitrogen per acre and P was 30 pounds of P_2O_5 per acre. The phosphorus was applied in the form of monoammonium phosphate because of its complete water solubility, and urea was added to give the correct amount of nitrogen per plot. All tillage and planting operations were completed by the farmer as a part of his regular field work. All of the experiments followed corn except at the Deuel county site, in which the crop followed barley. The experimental site was then selected in a uniform soil area and the fertilizer for the first date (at planting)

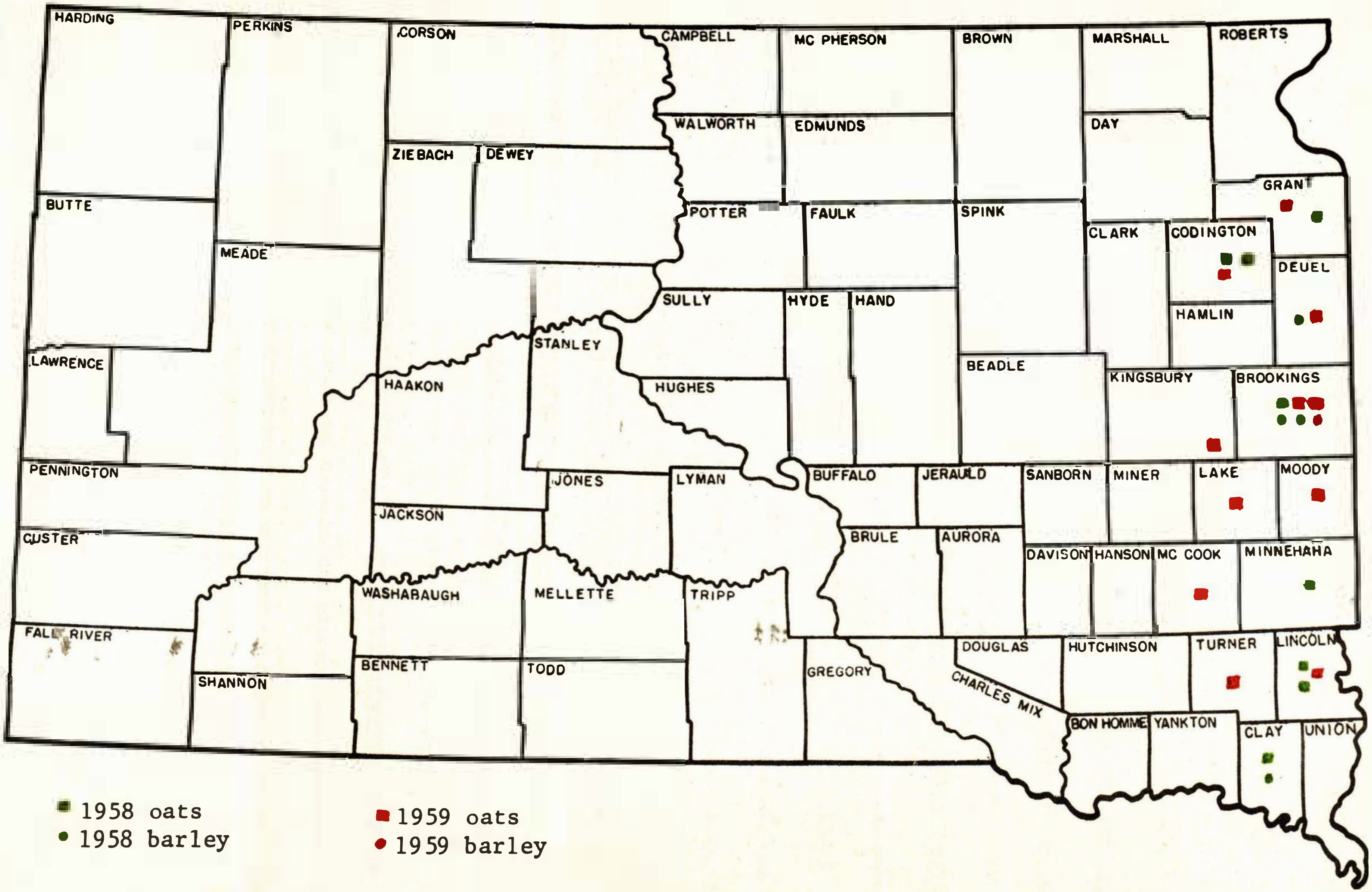

Figure 1. Locations of Field Experiments in 1958 and 1959

was applied. The fertilizer was spread on the individual plots by hand. The two later applications were at three and six weeks after planting. One experiment differed in that fertilizer was applied before tillage operations in addition to the other three times.

The small grain was harvested by hand and four square yard samples of grain were taken from each plot and composited for yield determinations. The samples of grain were then dried and threshed with a nursery threshing machine. The yields were calculated and recorded in terms of bushels per acre. The mean of the four replications was used to report the results.

The grain from three of the oat experiments and three of the barley experiments was saved for nitrogen analysis. The grain was analyzed by the Kjeldahl-Gunning method as given in the A.O.A.C. The nitrogen content as obtained from this analysis was multiplied by the factor 6.25 to obtain the protein content of the grain.

In 1959, the experimental design used in three of the four types of experiments was a randomized split plot with four replications. The dimensions of each individual plot were 16 feet by 20 feet. The 40 pound per acre rate of nitrogen was used to insure a detectable response in the small grain. The greater precision was again placed upon time of application in all of the experiments with the treatments in type A being check, N, and NP; where N was 40 pounds of nitrogen per acre and P was 30 pounds of P_2O_5 per acre, and the time of application was the same as in the 1958 experiments. The treatments in type B were check, N_1, and N_2; where N_1 and N_2 were 40 pounds of nitrogen applied per acre using urea and ammonium nitrate as carriers, respectively. A blanket application of phosphorus, as treble superphosphate, was spread on each plot at the rate of 80 pounds of P_2O_5 per acre to assure an adequate level of that element. The nitrogen was applied at planting, and two, four, and six weeks after planting.

The treatments in the type C experiments were check, NP_1 and NP_2 where N represented 40 pounds of nitrogen per acre in the form of ammonium nitrate. P_1 represented those plots where the phosphorus was applied at the same time as the nitrogen, and P_2 represented those plots where the phosphorus was all applied at planting. The rate of phosphorus was 40 pounds of P_2O_5 per acre, applied as treble superphosphate. The time of application of nitrogen was before tillage operations, at planting, and three and six weeks after planting.

The experimental design in the type D experiments was a randomized block type consisting of four replications and seven treatments per replication. The treatments used were check, N_1P, N_2P, N_3P, N_4P, N_5P, and N_6P; where the rate of phosphorus was 30 pounds of P_2O_5 per acre in the form of monoammonium phosphate with enough ammonium nitrate added to apply 40 pounds of nitrogen per acre. N_1P was applied at planting and the rest of the fertilizer was applied at two week intervals until 10 weeks after planting.

The grain was harvested with a power harvester, taking samples of 7.48 square yards per individual plot. The samples were handled in the same manner as the 1958 experiments. Grain samples from four experiments were kept and the protein content was determined. Plant samples were also taken from these experiments. The grain was removed and the remainder of the plant was analyzed for total nitrogen.

Climatological Information

The growing season in 1958 was characterized by below normal rainfall and below normal temperatures. At the beginning of the season the amount of subsoil moisture was good in most areas. Very little rainfall occurred in most areas until late May. Normal rainfall in June, plus cool temperatures throughout the season, made 1958 an excellent small grain year. A low incidence of disease was also noted. Local drought in areas where some of the experiments were located limited the yields of the small grain in five of the experiments.

In 1959, the growing season began with a very low supply of subsoil moisture. An early spring, characterized by a lack of rainfall, enabled the small grain to be planted earlier than normal. In May there was above average precipitation and temperatures were normal. A cold wave occurred about the middle of May and frost damaged the small grain as far south as Lake county. An infestation of green aphids also occurred in late May, but no insect damage to any of the experiments was noted. The first three weeks in June were characterized by above normal temperatures, little or no precipitation, and strong winds which severely damaged the grain in some experiments. Three experiments were abandoned because of continued dry weather in July, and little response to the fertilizer was noted in five more experiments. Weather conditions at the four remaining experimental sites were favorable for a response of the small grain to the fertilizer treatments.

RESULTS AND DISCUSSION

Tables I and II contain information on the location, variety of oats or barley, soil type, and fertility data of the surface layer of soil. Where there were two experiments in one county in the same season, each location was given a number. Any references in the text to these particular experiments will refer to the county where the experiment was located and the number as designated in Tables I and II.

Effect of Fertilizer on Yield of Oats and Barley

The results of the experiments with oats and barley and fertilizer treatments are recorded in Tables III, IV and V. All yield data were analyzed statistically and the least significant differences were recorded where significance was obtained.

Eight oats experiments were placed in various counties along the eastern border in South Dakota in 1958. The oats in five of these experiments gave a yield response to fertilizer which was significant at the one percent level. The other three experiments were in local drouth areas, and the yields of all individual plots in an experiment were essentially the same.

In the experiments where the yield increases due to fertilizer treatments were significant, the soil test revealed low levels of available phosphorus. Nitrogen alone caused increases over the check in three of the five experiments whereas a combination of nitrogen and phosphorus caused yield increases in all five of these experiments. The increase in yield of oats due to the combination of nitrogen and phosphorus over

TABLE I. LOCATION, CROP VARIETY, SOIL TYPE, AND FERTILITY DATA OF THE EXPERIMENTAL SITES, 1958

County	Variety	Soil type	Fertility data of the 0-7 inch layer of soil: Pounds of available P_2O_5/acre*	Pounds of available K_2O/acre*	% total nitrogen
	Oats				
Brookings	Garry	Vienna loam	8.1	328	.36
Clay	Cherokee	Trent silt loam	15.7	692	.23
Codington (Location No. 1)	Garry	Vienna silt loam	13.9	501	.26
Codington (Location No. 2)	Waubay	Kranzburg loam	12.6	336	.22
Grant	Ransom	Barnes loam	19.7	680	.21
Lincoln (Location No. 1)	Ajax	Trent silt loam	18.9	657	.26
Lincoln (Location No. 2)	Waubay	Kranzburg silt loam	54.6	782	.26
Minnehaha	Bond	Moody silt loam	10.8	485	.18
	Barley				
Brookings (Location No. 1)	Kindred	Kranzburg silt loam	58.1	430	.27
Brookings (Location No. 2)	Trail	Vienna loam	10.8	446	.36
Clay	Kindred	Trent silt loam	19.7	785	.20
Deuel	Kindred	Kranzburg silt loam	7.1	289	.31

* Analyzed by the Soil Testing Laboratory, South Dakota State College, Brookings, South Dakota.

TABLE II. LOCATION, CROP VARIETY, SOIL TYPE, AND FERTILITY DATA OF THE EXPERIMENTAL SITES, 1959

County	Variety	Soil type	Fertility data of the 0-7 inch layer of soil: Pounds of available P_2O_5/acre*	Pounds of available K_2O/acre*	% total nitrogen
	Oats				
Brookings (Location No. 1)	Burnett	Kranzburg silt loam	13.9	190	.25
Brookings (Location No. 2)	Garry	Vienna loam	12.6	176	.36
Codington	Rodney	Vienna sandy clay loam	13.2	341	.20
Deuel	Garry	Kranzburg silt loam	12.6	176	.29
Grant	Minhafer	Barnes loam	37.8	440	.18
Kingsbury	Waubay	Poinsett silt loam	17.5	394	.19
Lake	Waubay	Poinsett silty clay loam	9.4	238	.19
Lincoln	Cherokee	Trent silt loam	25.5	203	.22
McCook	Sauk	Glacial till silt loam	24.4	384	.20
Moody	Waubay	Trent silt loam	14.3	256	.29
Turner	Ransom	Glacial till loam	21.7	224	.20
	Barley				
Brookings	Kindred	Kranzburg silt loam	88.2	251	.22

* Analyzed by the Soil Testing Laboratory, South Dakota State College, Brookings, South Dakota.

TABLE III. AVERAGE EFFECT OF FERTILIZER APPLICATION (ALL DATES) ON YIELD OF OATS, 1958

Treatment	Brookings County	Clay County	Codington County No. 1	Codington County No. 2	Grant County	Lincoln County No. 1	Lincoln County No. 2	Minnehaha County
0-0-0[1/]	25.5[2/]	51.3	66.5	43.3	34.4	48.8	42.0	31.4
20-0-0	25.3	48.8	64.0	41.3	46.6	48.5	41.3	38.9
40-0-0	25.6	47.8	63.5	43.9	55.9	53.5	42.1	43.0
20-30-0	32.5	53.6	78.4	48.4	49.7	61.1	44.6	40.3
40-30-0	34.0	57.1	76.5	48.5	58.0	62.9	43.7	46.9
F value	7.79**	0.52	5.74**	0.83	20.24**	9.21**	0.41	18.27**
L.S.D.[3/]	6.8		8.4		11.1	10.1		7.1

1/ Pounds of nitrogen, P_2O_5 and K_2O per acre, respectively.

2/ Yield in bushels per acre.

3/ Least significant difference (5 percent level).

** Significant at 1 percent level.

TABLE IV. AVERAGE EFFECT OF FERTILIZER APPLICATION (ALL DATES) ON YIELD OF OATS, 1959

Treatment	Type of experiment and location								
	Type A		Type B			Type C	Type D		
	Lake Co.	Turner Co.	Brookings Co. No. 1	Kingsbury Co.	Lincoln Co.	Brookings Co. No. 2	Deuel Co.	McCook Co.	Moody Co.
0-0-0[1]	20.2[2]	29.6	41.2	24.3	39.1	24.4	31.3	21.0	30.3
40-0-0	19.8	28.6							
40-30-0	20.0	29.8					40.5	29.1	30.5
40-40-0						24.7			
0-80-0			43.6	23.2	53.6				
40-80-0			54.3	26.4	53.0				
F value	.01	.04	6.49*	1.84	4.28	0.26	25.00**	3.04*	1.08
L.S.D.[3]			8.9				4.9	7.4	

1/ Pounds of nitrogen, P_2O_5 and K_2O per acre, respectively.

2/ Yield in bushels per acre.

3/ Least significant different (5 percent level).

* Significant at 5 percent level.

** Significant at 1 percent level.

TABLE V. AVERAGE EFFECT OF FERTILIZER APPLICATION (ALL DATES) ON YIELD OF BARLEY, 1958

Treatment	Brookings County No. 1	Brookings County No. 2	Clay County	Deuel County
0-0-0[1/]	54.5[2/]	26.9	41.3	29.9
20-0-0	49.4	29.6	38.3	34.0
40-0-0	51.7	29.6	44.4	34.9
20-30-0	52.8	41.2	43.6	40.0
40-30-0	54.2	41.4	47.2	43.1
F value	0.98	12.72**	2.88	11.29**
L.S.D.[3/]		11.1		8.5

1/ Pounds of nitrogen, P_2O_5 and K_2O per acre, respectively.

2/ Yield in bushels per acre.

3/ Least significant different (5 percent level).

** Significant at 1 percent level.

that produced by nitrogen alone varied from three to 14 bushels per acre. In the Codington County No. 1 experiment, the yield of oats was not increased by the addition of nitrogen but was increased 11 bushels per acre where nitrogen and phosphorus were applied. In the Brookings and Lincoln County No. 1 experiments where drouth affected the yields to some extent, there was little or no response to either rate of nitrogen, but a seven to 14 bushel increase resulted where a combination of nitrogen and phosphorus was applied. The Grant and Minnehaha County experiments, conversely, evidenced increases of seven to 21 bushels per acre due to the nitrogen; and the combination of nitrogen and phosphorus caused about three more bushels per acre than the nitrogen alone. Evidently nitrogen was more of a limiting factor than was phosphorus in these two experiments.

The effect of rates of nitrogen on the yield of oats was varied. In the Minnehaha, Grant and Lincoln County No. 1 experiments the yield was higher in those plots with the 40 pound rate than with the 20 pound rate of nitrogen, both with and without phosphorus. In the other two experiments where there was a significant response to the fertilizer, there was little or no variation between the 20 and 40 pound rates of nitrogen, whether applied alone or in combination with phosphorus.

Eleven oats experiments were placed in 10 counties in 1959. Two of these experiments, those located in Codington and Grant Counties, were abandoned because extreme drought conditions and high temperatures caused almost a complete crop failure in those counties.

Six experiments gave results which showed no significant response to the fertilizer treatments. High temperatures and low soil moisture levels precluded a response at five of these locations. The response of oats to the fertilizer treatments in the Lincoln County experiment was also not significant. The object of this experiment was to compare the effect of two nitrogen carriers on the yield of oats. Phosphorus at a rate of 80 pounds of P_2O_5 per acre was applied to all plots in the experiment. A yield sample from outside the experimental plot area was taken to determine the response due to phosphorus alone. As shown in Table IV, the application of phosphorus alone increased the yield from 39.1 to 53.4 per acre. The response due to the nitrogen and phosphorus was essentially the same as that due to phosphorus only.

Three experiments, those located in Brookings, Deuel and McCook Counties, produced yield results which showed significant responses due to the fertilizer. Although these experiments were also subject to above normal temperatures in early June, they were located in areas which received above average amounts of rainfall for that particular year. Precipitation measurements which were recorded for the Brookings and Deuel County experiments showed that 9.1 and 11.5 inches of precipitation fell on those experimental sites, respectively. From these results, it was noted that while the high temperatures in June undoubtedly decreased the small grain yields in 1959, those small grains in areas which received average amounts of rainfall responded to the fertilizer treatment, while those grains in areas of less rainfall did not.

Four barley experiments were placed in three counties in 1958. The fertilizer caused significant yield increases in two of these experiments. The soil test of the Brookings County No. 1 experiment showed a high level of available phosphorus. The soil management of this experimental site was above average. Soil moisture relations and temperatures were also favorable at that location and the yields of all individual plots were essentially the same. Dry weather and high temperatures in July precluded any significant response to the fertilizer in the Clay County experiment.

In the Brookings County No. 2 and the Deuel County experiments, the soil tests disclosed low levels of available phosphorus. There was no significant response due to the application of nitrogen alone. The increase in yield due to the application of both nitrogen and phosphorus was six to 12 bushels more than the increase due to nitrogen alone. This agrees with the results which were obtained in those oats experiments in which there were low levels of available soil phosphorus. Barley responds well to phosphorus applications, and these results substantiate this fact. The 40 pound per acre rate of nitrogen did not increase the yield of barley more than did the 20 pound per acre rate. The 30 pound per acre rate of phosphorus may not have provided sufficient phosphorus for maximum yield and thus limited the response to nitrogen. Climatic conditions may also have been a factor in limiting the response to nitrogen at the higher rate.

Only one barley experiment was conducted in 1959. That experiment was located in Brookings County and was abandoned. The combination of frost, drouth, and high temperatures resulted in a very thin stand and the farmer plowed it up in late June.

Effect of Time of Fertilizer Application on Yield of Oats and Barley

The effect of the time of fertilizer application on the yield of oats and barley in 1958 is shown in Table VI and Figures 2 and 3. The yield results from the application of the 40 pound rate of nitrogen with phosphorus were used in Figures 2 and 3. In all of the seven experiments in which there was a significant response to the fertilizer treatments, there was not enough variation in yield due to the time of application to be statistically significant.

The first application in six of the experiments was top dressed right after the farmer had planted the grain and the soil was not worked after the fertilizer had been applied. The second application was top dressed three weeks after planting, when the grain averaged two inches

TABLE VI. EFFECT OF TIME OF FERTILIZER APPLICATION ON YIELD OF OATS AND BARLEY, 1958

Location	Time of fertilizer application[1]	Treatment					F value
		0-0-0[2]	20-0-0	40-0-0	20-30-0	40-30-0	
Oats							
	0		23.1	24.4	32.9	38.6	
Brookings	1		28.2	32.4	31.9	30.0	
County	2	25.5[3]	24.2	21.1	34.8	34.8	0.43
	3		26.0	24.3	30.8	32.4	
Codington	1		63.8	62.2	77.3	77.7	
County No. 1	2	66.5	61.2	66.0	78.2	77.5	0.14
	3		67.1	62.3	79.7	73.3	
Grant	1		44.9	54.0	51.9	55.9	
County	2	34.4	51.5	61.0	46.9	64.2	3.23
	3		43.9	52.7	50.3	53.9	
Lincoln	1		46.9	49.4	61.3	60.5	
County No. 1	2	48.8	49.9	51.4	63.6	61.4	1.86
	3		47.8	49.6	58.4	55.8	
Minnehaha	1		38.3	42.9	41.0	47.7	
County	2	31.4	40.6	42.7	37.7	47.8	0.41
	3		37.9	43.5	44.5	44.0	
Barley							
Brookings	1		31.1	32.4	43.7	41.5	
County No. 2	2	26.9	27.1	27.8	38.1	42.2	1.56
	3		30.8	24.8	42.9	41.8	
Deuel	1		35.2	34.5	44.1	45.4	
	2	29.9	33.2	35.2	39.1	44.8	0.62
	3		33.6	34.9	36.8	42.0	

1/ 0, 1, 2, 3 denotes fertilizer applied before tillage operations, at planting, 3 weeks after planting and 6 weeks after planting respectively.

2/ Pounds of nitrogen, P_2O_5 and K_2O applied per acre, respectively.

3/ Bushels per acre.

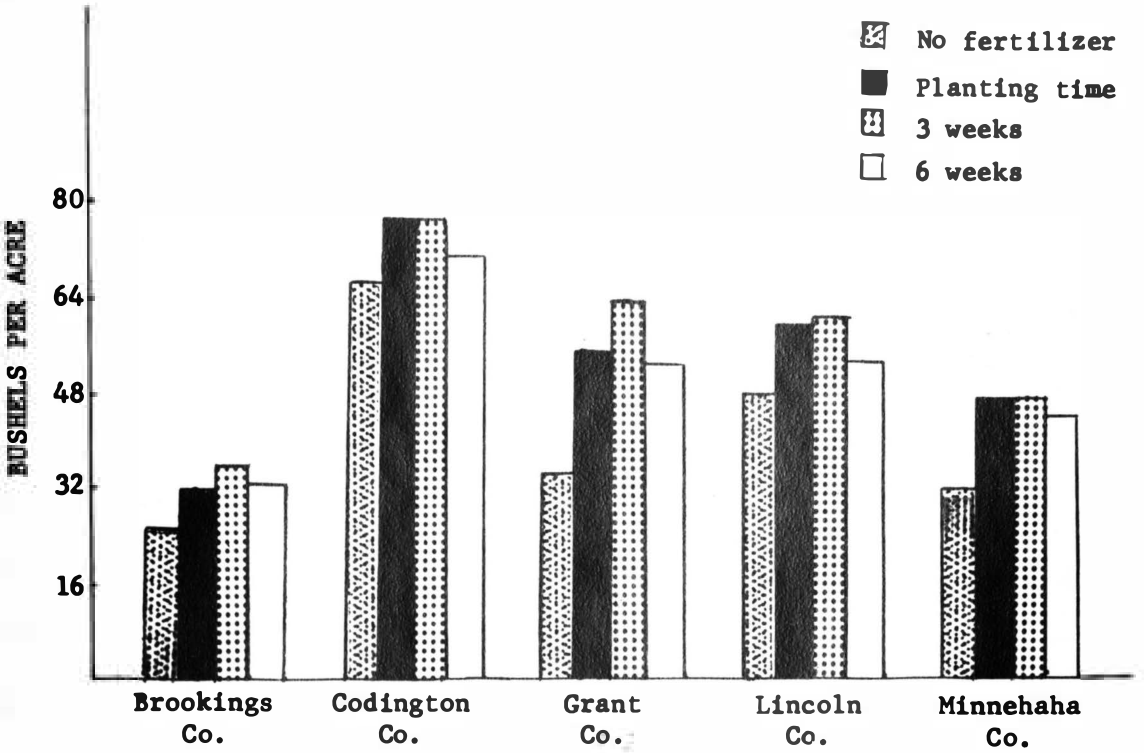

Figure 2. Effect of Time of Fertilizer Application on Yield of Oats, 1958

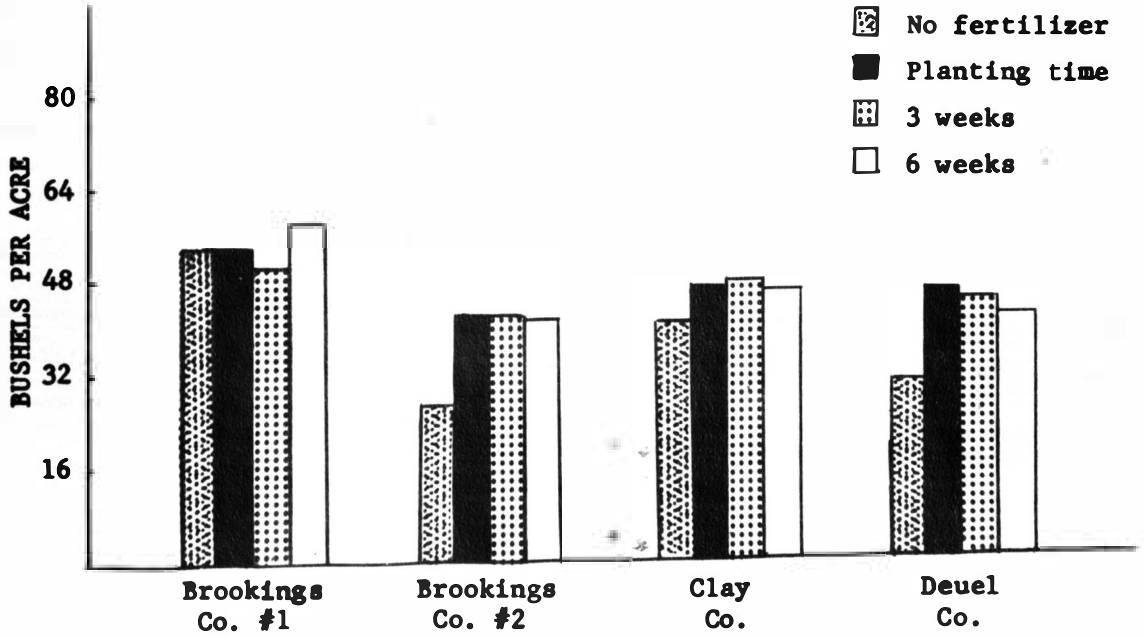

Figure 3. Effect of Time of Fertilizer Application on Yield of Barley, 1958

in height. The third application was top dressed six weeks after planting, when the grain averaged five inches in height. This third application was from one to two weeks before the grain was in the boot stage, or about three weeks before heading.

Rainfall after the last application may have brought the water soluble fertilizer into the region of root absorption. According to Burd (4), nutrients are absorbed by the plants at a progressively increasing rate until heading. If the fertilizer applied at the later dates was in the region of root absorption before heading, enough of the applied nutrients could have been absorbed by the plants to produce the same yields as those plots which received the fertilizer at planting.

These results agree with those reported by Hoagland (12) who found that the presence of adequate plant nutrients in the first eight to 10 weeks of the growth cycle of barley affected the yield but suitable concentrations of these nutrient elements after this period had no effect on the yield even though they were absorbed by the plant.

An additional application was included in the Brookings County oats experiment. This application was broadcast before all planting operations began, so the fertilizer was incorporated with the soil. In the statistical analysis of this experiment, the time of application and treatment interaction was found to be significant, even though the time of application was not. This indicated that the time of application produced significant differences with some of the treatments.

Where nitrogen at the 40 pound rate was incorporated before planting, the yield was 24.4 bushels per acre and where it was top dressed after planting, the yield was 32.4 bushels per acre. The yields on plots where the applications were made three and six weeks after planting were 21.1 and 24.3 bushels per acre, respectively. When the 20 pound rate of nitrogen was incorporated with the soil, the yield was 23.1 bushels per acre; when it was top dressed after planting the yield was 28.2 bushels per acre. These results tend to agree with Robertson et al. (25), who found that the nitrogen which was top dressed produced higher yields than did the nitrogen which was plowed down. Their opinion was that the nitrogen which was incorporated into the soil was immobilized in the decay processes of the cornstalk residue. This reasoning may also account for the higher yields which occurred when nitrogen was surface applied after planting in the Brookings County experiment.

An application of nitrogen at the rate of 40 pounds per acre, with adequate phosphorus included, caused a yield of 38.6 bushels per acre when the fertilizer was incorporated into the soil. When this same fertilizer treatment was broadcast on the surface right after planting, the yield was 31.3 bushels per acre. The soil on this experimental site was very low in available phosphorus. The soil moisture level was also very low at the beginning of the experiment. Little or no rainfall occurred to leach the applied mono-ammonium phosphate into the region of root absorption until the first week in June; and it may have been too late in the growth cycle of the plants for the applied phosphorus to be of benefit. Consequently the yield of oats was greater where the phosphorus was mixed with the soil than where it was surface applied. Since phosphorus moves very slowly in the soil, the incorporation of any fertilizer which contains phosphorus into the soil is probably better than top dressing, especially in a year with little rainfall during the first half of the growing season. The results of this experiment appear to substantiate this theory.

In 1959, four types of experiments were designed to measure the effect of time of fertilizer application on the yield of oats and barley. The results of the effect of time of fertilizer application on the yield of oats in three experiments are given in Table VII and Figures 4 and 5. There was no significant variation in yield due to the fertilizer treatment or to the time of fertilizer application in the other experiments.

In the Deuel County experiment, a significant increase in yield resulted from the application of fertilizer at planting and at two and four weeks after planting, where the yield increases were 16.4, 10.6, and 11.8 bushels per acre, respectively. The application of fertilizer at six, eight and 10 weeks after planting did not significantly increase the yield.

The effect of the time of fertilizer application on the yield of oats in McCook County largely agreed with the Deuel County experiment. In this experiment however, the application six weeks after planting caused a significant increase in yield while the application two weeks earlier did not. There was a thin stand of grain in two of the four plots where fertilizer had been applied four weeks after planting which probably decreased the average yield of the four replications enough to make this response not statistically significant. The high temperatures in June associated with a lower level of soil moisture reduced the amount of response in this experiment. In the Deuel County experiment, where climatic conditions were more favorable, the degree of response was greater.

TABLE VII. EFFECT OF TIME OF FERTILIZER APPLICATION ON YIELD OF OATS, 1959

Time of fertilizer application	Location			
	Deuel Co.	McCook Co.	Brookings Co.	
			Ammonium nitrate	Urea
No fertilizer	31.3[1/]	21.0	43.6	43.6
Applied at planting	47.7	29.4	50.2	53.6
2 weeks after planting	41.9	33.7	52.9	51.4
4 weeks after planting	43.1	26.6	54.9	51.5
6 weeks after planting	32.9	29.1	62.2	57.1
8 weeks after planting	33.7	28.2		
10 weeks after planting	34.0	27.9		
F value	25.00**	3.04*	4.58*	4.58*
L.S.D.[2/]	4.9	7.4	6.6	6.6

1/ Yield in bushels per acre.

2/ Least significant difference (5 percent level).

* Significant at 5 percent level.

** Significant at 1 percent level.

The results of the effect of two carriers of nitrogen top dressed on oats at various dates in the Brookings County No. 1 experiment are found in Table VII. This table shows that both carriers of nitrogen fertilizer applied six weeks after planting caused higher yields than did any other application. The yield of oats where ammonium nitrate was applied was 62.2 bushels per acre and where urea was applied, the yield was

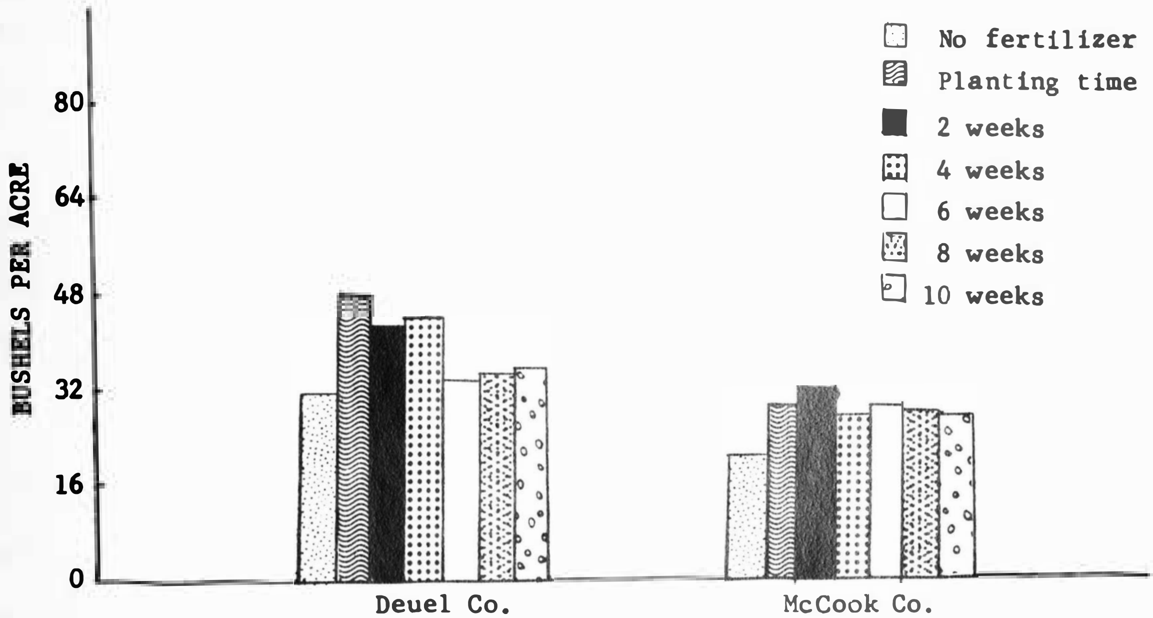

Figure 4. Effect of Time of Fertilizer Application on Yield of Oats, 1959

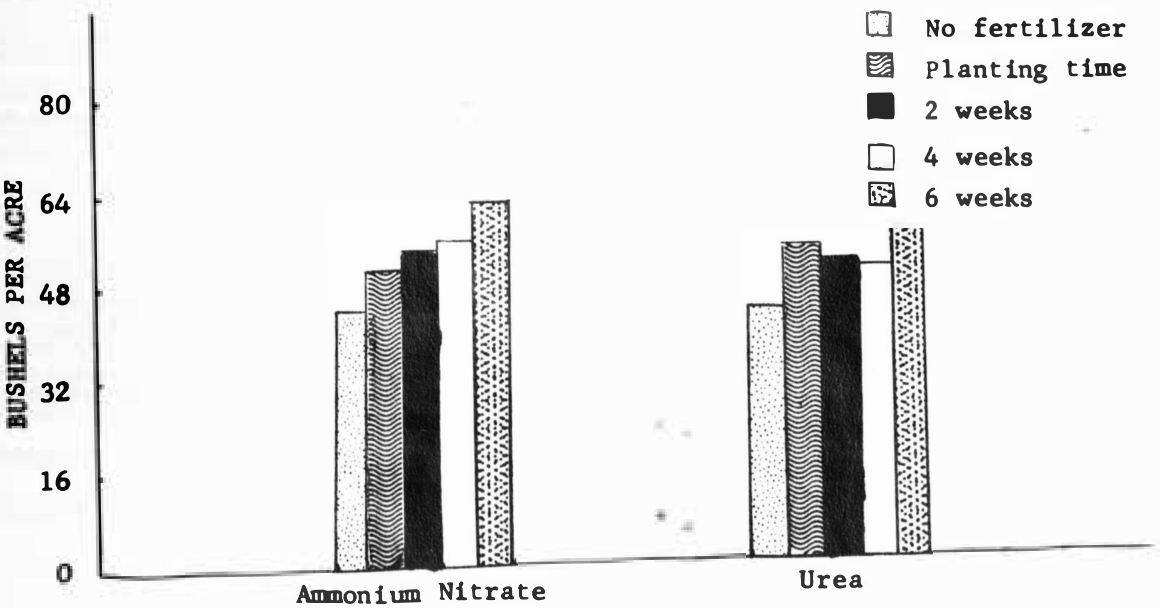

Figure 5. Effect of Time of Application of Two Carriers of Nitrogen on Yield of Oats in Brookings County, 1959

57.1 bushels per acre. These yields were 12.0 and 3.5 bushels per acre, respectively, higher than when the same carrier was applied at planting. Although it appears from these results that ammonium nitrate is a better carrier of nitrogen to use when delaying the application, the author is of the opinion that there was not enough evidence to warrant this conclusion.

In combining the data for both years, there is good indication that the application of fertilizer at various times up to six weeks after planting caused increases in yield which were not significantly different. The growing conditions during the two seasons were radically different. Both oats and barley responded to fertilizer treatments in most locations with favorable growing conditions in 1958, but there was no significant variation in yield due to the time of application. In 1959, the same relative response from applications ranging from planting to six weeks after planting occurred with growing conditions which were not as favorable; although a smaller percent of experiments showed this response.

It is interesting to note, however, that the results of most of the experiments in 1958 show a trend towards a smaller yield increase from the fertilizer application six weeks after planting than from the earlier applications. This trend is well illustrated by the Deuel County experiment in 1959, where there was a marked decline in the yield increase when the fertilizer was applied later than four weeks after planting. It appears that at some time in the period four to eight weeks after planting, the marked decline in yield increase occurs. This varies especially with the rainfall distribution pattern. If a rain occurred right after a fertilizer application made six weeks after planting, the fertilizer may reach the zone of root absorption in time to cause a yield increase as large as one produced by a fertilizer application at planting. In the event the rainfall did not occur immediately after the late application however, the fertilizer may not reach the zone of root absorption in time to produce a significant yield increase. The stage of plant growth and climatic conditions, especially the amount and distribution of rainfall and temperature, will affect the relative crop response to the various dates of fertilizer application.

Effect of Time of Fertilizer Application on Protein Content of Oats and Barley

The effect of the time of fertilizer application on the protein content of oats and barley in 1958 is shown in Table VIII and Figures 6 and 7. The variation in protein content as shown in Figures 6 and 7 resulted from the effect of the application of the 40 pound rate of nitrogen with phosphorus included. The application of nitrogen alone increased the protein content of the grain in every instance except in the 20 pound rate of the Grant County oats experiment. In this experiment, the application of this fertilizer treatment increased the yield of oats an average of 12.2 bushels per acre. Evidently there was not enough available nitrogen with the 20 pound rate to increase the protein content in addition to the yield. The 40 pound rate of nitrogen increased the yield an average of 9.3 bushels per acre over the 20 pound rate in this experiment. With this treatment, however, the protein content also increased. Table IX shows the effect of time of application of the various treatments on the total protein produced per acre. The protein production was

TABLE VIII. EFFECT OF TIME OF FERTILIZER APPLICATION ON PROTEIN CONTENT OF OATS AND BARLEY, 1958

Location	Time of fertilizer application[1/]	Treatment				
		0-0-0[2/]	20-0-0	40-0-0	20-30-0	40-30-0
Oats						
	0	12.64[3/]	13.32	13.91	12.42	13.04
Brookings	1		12.70	14.43	12.98	13.23
County	2		13.20	14.68	13.23	13.44
	3		13.39	14.40	12.45	13.07
Grant	1		13.70	15.05	14.23	15.50
County	2	14.28	14.22	14.81	14.22	15.05
	3		13.72	14.56	13.86	15.52
Minnehaha	1		12.24	14.91	11.99	12.08
County	2	10.93	12.02	13.88	11.52	11.84
	3		12.18	13.39	11.43	12.64
Barley						
Brookings	1	13.04	14.19	13.51	13.10	13.71
County No. 1	2		13.66	13.51	13.60	13.75
	3		14.00	13.10	13.13	13.50
Brookings	1		12.67	12.79	11.55	12.54
County No. 2	2	12.14	12.87	13.04	11.65	12.33
	3		12.92	13.32	12.20	12.58
Deuel	1	10.04	11.21	11.65	11.03	10.94
County	2		11.03	11.43	10.94	10.81
	3		11.14	12.58	10.53	11.91

1/ 0, 1, 2, 3 denotes fertilizer applied before tillage operations, at planting, 3 weeks after planting, and 6 weeks after planting, respectively.

2/ Pounds of nitrogen, P_2O_5 and K_2O per acre, respectively.

3/ Percent protein.

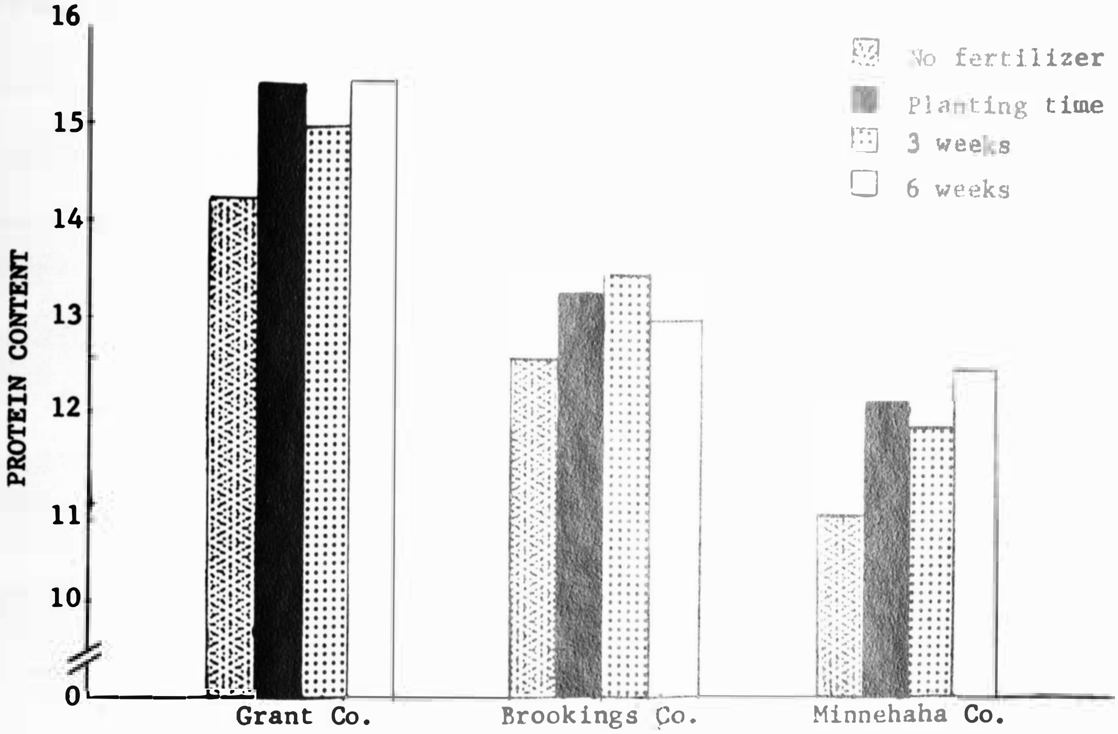

Figure 6. Effect of Time of Fertilizer Application on the Protein Content of Oats, 1958

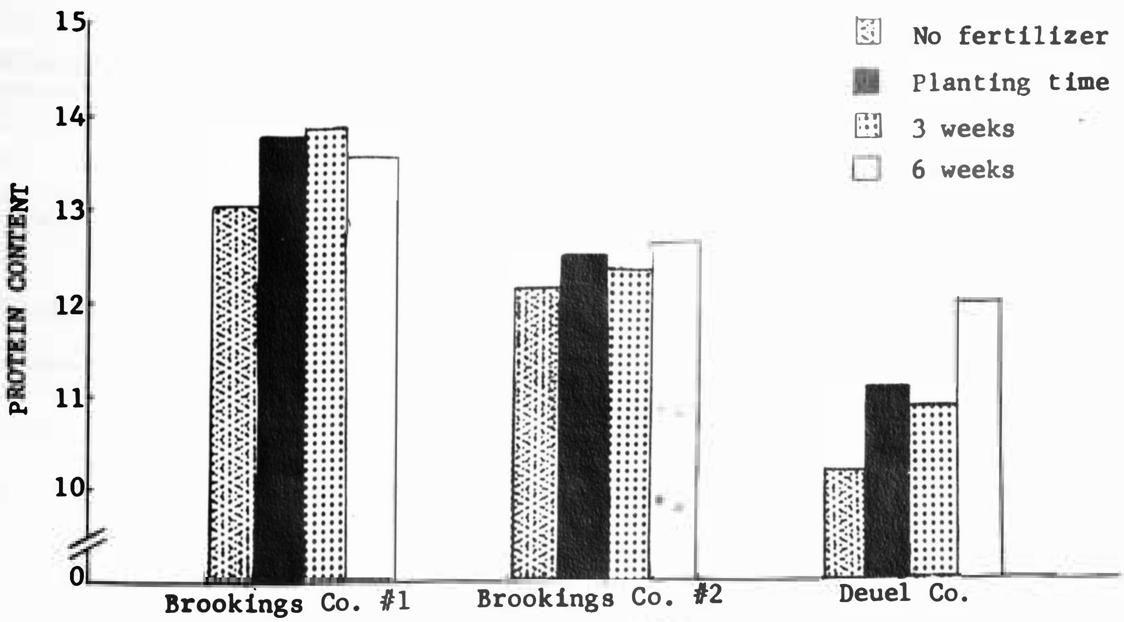

Figure 7. Effect of Time of Fertilizer Application on the Protein Content of Barley, 1958

TABLE IX. EFFECT OF TIME OF FERTILIZER APPLICATION ON TOTAL PROTEIN PRODUCED PER ACRE WITH OATS AND BARLEY, 1958

Location	Time of fertilizer application1/	Treatment				
		0-0-0 2/	20-0-0	40-0-0	20-30-0	40-30-0
Oats						
Brookings County	0		108	116	139	181
	1	110 3/	125	159	139	145
	2		111	105	157	164
	3		118	119	134	148
Grant County	1	177	215	284	266	312
	2		264	316	227	338
	3		205	261	244	284
Minnehaha County	1		159	214	170	193
	2	120	166	199	148	187
	3		155	192	172	178
Barley						
Brookings County No. 1	1	327	327	327	314	333
	2		302	308	362	325
	3		321	315	300	355
Brookings County No. 2	1	154	185	191	237	245
	2		164	167	209	242
	3		187	152	246	247
Deuel County	1	138	182	185	219	224
	2		168	183	192	218
	3		172	202	178	225

1/ 0, 1, 2, 3 denotes fertilizer applied before tillage operations, at planting, 3 weeks after planting, and 6 weeks after planting, respectively.

2/ Pounds of nitrogen, P_2O_5 and K_2O per acre, respectively.

3/ Pounds of protein per acre.

determined by multiplying the grain yield by the protein content of each treatment. This table shows that the total protein production was increased by all fertilizer treatments in all of the experiments except the Brookings County No. 1 experiment where the soil management was above average and there was no response to the fertilizer treatment.

In comparing the effect of the two rates of nitrogen, those plots on which the 40 pound rate of nitrogen was applied produced an average of 34 pounds more protein per acre and also increased the protein content of oats an average of 1.34 percent more than where the 20 pound rate was applied. On barley, however, the same comparison showed an average increase of 0.49 percent protein and a gain of five pounds of protein per acre on two of the experiments. In the Brookings County No. 1 experiment the 20 pound rate increased the protein content an average of 0.50 percent more than did the 40 pound rate and there was no difference in the average amount of total protein produced. As stated before, the grain at this location showed no response to fertilizer.

The protein content of the grain produced from plots where both nitrogen and phosphorus were applied was lower than where nitrogen was applied alone. Those plots where phosphorus was included in the fertilizer treatment produced greater yield increases, however. More nitrogen would be required to maintain the protein content of the increased yield of grain. If the required nitrogen was not available, the protein content would then decrease. This decrease in protein content occurred in most instances when phosphorus was applied with the nitrogen. In comparing the increase in total protein produced in the barley experiments, more protein was produced per acre with phosphorus added than with nitrogen alone. Barley responds well to phosphorus application, and the increase in yield more than offset the decrease in protein content. In oats, nitrogen alone increased the total protein production to a greater extent in some instances and the combination of nitrogen and phosphorus increased the total protein production in other instances. The 40 pound rate of nitrogen was effective in producing more pounds of protein per acre and a higher protein content than was the 20 pound rate both when applied alone or in combination with phosphorus.

The protein content of the grain generally did not increase with the delay in fertilizer application, as was reported in the literature. The protein content of the grain from plots where the fertilizer was not applied until after heading was reported to be higher than when the fertilizer was applied early in the growth cycle of the plant. In the experiments conducted in 1958, the latest fertilizer applications were applied six weeks after planting, or about three weeks before heading. The fertilizer from these applications was evidently in the root zone early enough to cause increases in the yield rather than the protein content.

The effect of time of fertilizer application on the protein content of oats in 1959 is recorded in Table X and Figures 8 and 9. Fertilizer increased the protein content in every instance. These results agree with those in 1958, where the 40 pound rate of nitrogen also increased the protein content.

The effect of the time of fertilizer application on the protein content of oats varied between experiments. In the Deuel County experiment, the protein content of the oats decreased with the delay of fertilizer application. In the McCook County experiment, where the yield

TABLE X. EFFECT OF TIME OF FERTILIZER APPLICATION ON THE PROTEIN CONTENT OF OATS AND TOTAL PROTEIN PRODUCTION PER ACRE, 1959

Location		None	Time of fertilizer application: at planting	2 weeks after	4 weeks after	6 weeks after	8 weeks after	10 weeks after
Deuel County	% protein	10.59	12.25	12.79	11.19	11.90	11.03	10.87
	total protein[1]	106.1	185.4	171.4	154.3	125.3	118.9	118.2
McCook County	% protein	12.09	13.98	12.57	13.69	12.89	14.17	13.94
	total protein	81.2	131.5	135.6	116.5	120.0	127.9	124.4
Brookings County No. 1 (ammonium nitrate)[2]	% protein	11.67	12.22	12.79	11.77	11.77		
	total protein	188.3	227.0	250.3	232.6	278.6		
Brookings County No. 1 (urea)[2]	% protein	11.67	12.18	11.61	13.11	12.70		
	total protein	188.3	248.1	220.8	243.1	264.7		
Turner County (40-0-0)[3]	% protein	12.70	13.46			14.71		
	total protein	120.3	137.0			124.3		
Turner County (40-30-0)[3]	% protein	12.70	13.88			14.52		
	total protein	120.3	135.5			134.7		

1/ Pounds of protein produced per acre with oats.

2/ Denotes the carrier of nitrogen used.

3/ Pounds of applied nitrogen, P_2O_5 and K_2O, respectively.

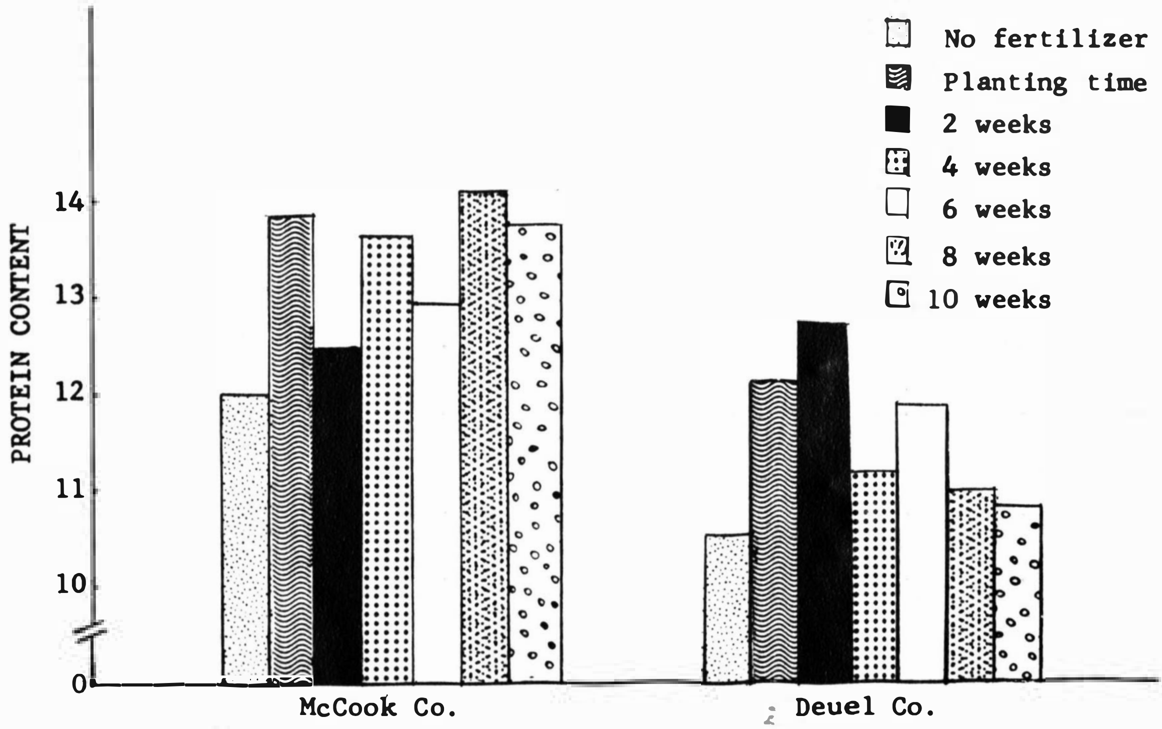

Figure 8. Effect of Time of Fertilizer Application on the Protein Content of Oats, 1959

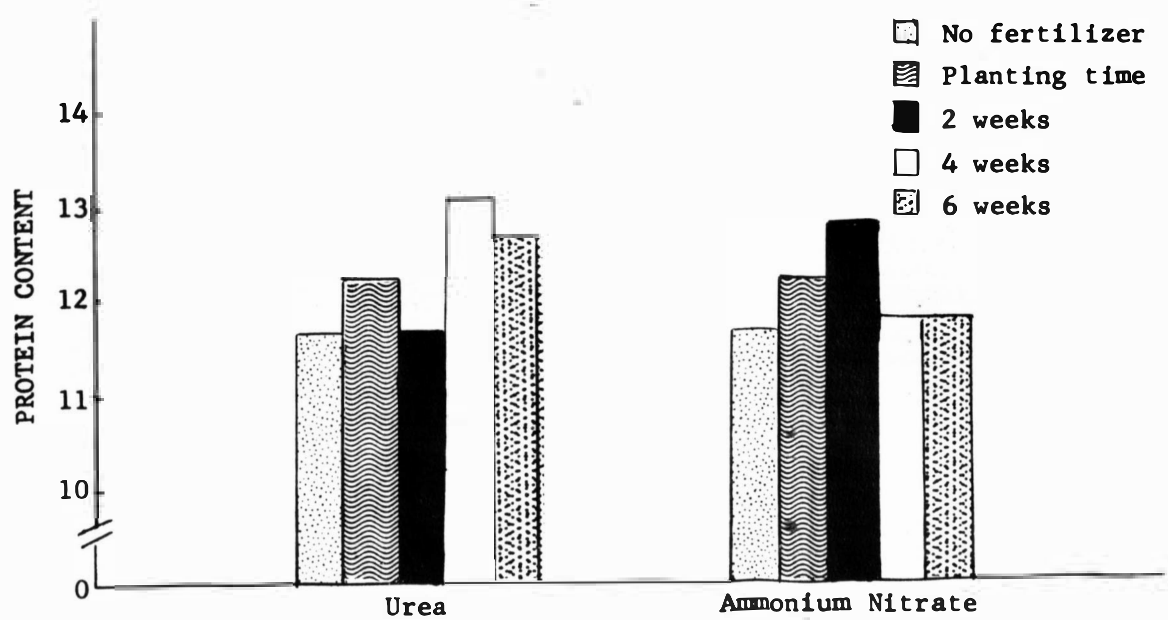

Figure 9. Effect of Time of Application of Two Carriers of Nitrogen on the Protein Content of Oats in Brookings County, 1959

of grain did not vary as much, the protein content of oats varied from 12.57 percent with the application two weeks after planting to 14.17 percent with the application eight weeks after planting. In the Turner County experiment, where there was little or no response to fertilizer and no variation in yield due to time of fertilizer application, the protein content increased with the delay in application.

The effect of time of application on the total protein produced is probably a better comparison than the protein content because a plant must integrate all factors in its environment. If more tillers were produced and the yields were increased, for instance, the protein content of the grain produced would be lower than that of a plot where the yield was smaller, if the same amount of nitrogen were available to both plots.

On this basis, the total protein produced per acre decreased steadily with the time of application in the Deuel County experiment, and the same trend was observed in the McCook and Turner Counties experiments. In the Brookings County No. 1 experiment, the total protein production was highest in those plots where the fertilizer was applied six weeks after planting. This fertilizer application caused a significant increase in yield with no appreciable decrease in protein content.

From these results, it appears that the protein production by oats and barley decreases when the application of fertilizer is delayed. The greatest amount of total protein results when the fertilizer is applied at planting. The decrease is gradual until the fertilizer application date is four to six weeks after planting, or later, when a marked decline occurs. The length of time between planting and fertilizer application before the occurrence of this marked decline depends mainly upon the rainfall distribution and stage of plant growth.

Effect of Time of Fertilizer Application on the Recovery by Oats of Applied Nitrogen

Another measure of the effect of the time of fertilizer application is the amount of recovery by the crop of the applied nitrogen. Table XI shows the effect of delaying the fertilizer application on the percent recovery by oats of the applied nitrogen. The grain and the straw produced from the various fertilizer treatments were analyzed for total nitrogen. From the nitrogen content and the amount of grain and straw produced by the various fertilizer treatments, it was possible to determine the increase in the amount of total nitrogen taken up by the plants. The percent recovery of the application of 40 pounds of nitrogen was then determined. Table XI shows that the percent recovery of applied nitrogen was highest when the fertilizer was applied at planting and it generally decreased with the delay in application of the fertilizer. A sharp decline in the percent recovery of applied nitrogen may occur when the nitrogen is applied later than six weeks after planting. The results of these experiments are in agreement with the logical assumption that more nitrogen would be recovered by the plants when the nitrogen is applied early in the growth cycle.

TABLE XI. EFFECT OF TIME OF FERTILIZER APPLICATION ON THE RECOVERY BY OATS OF APPLIED NITROGEN, 1959

Time of fertilizer application	Total weight of grain (pounds per acre)	Nitrogen content of grain (%)	Total weight of straw (pounds per acre)	Nitrogen content of straw (%)	Recovery of applied nitrogen (%)
<u>Deuel County</u>					
No fertilizer	1002	1.694	1134	0.440	
Applied at planting	1526	1.944	1719	0.461	39.1
2 weeks after planting	1341	2.046	1590	0.461	32.0
4 weeks after planting	1379	1.790	1580	0.471	25.4
6 weeks after planting	1024	1.904	1196	0.486	9.7
8 weeks after planting	1078	1.765	1220	0.578	10.3
10 weeks after planting	1088	1.740	1228	0.629	11.7
<u>McCook County</u>					
No fertilizer	672	1.919	1034	0.512	
Applied at planting	941	2.237	1881	0.553	32.9
2 weeks after planting	1078	2.011	1864	0.507	32.2
4 weeks after planting	851	2.190	1588	0.645	26.5
6 weeks after planting	931	2.062	1708	0.635	29.4
8 weeks after planting	902	2.267	1347	0.619	26.3
10 weeks after planting	893	2.230	1378	0.619	25.1

SUMMARY AND CONCLUSIONS

Fertilizer experiments were conducted in various parts of eastern South Dakota in 1958 and 1959 to determine the effect of the time of fertilizer application on the yield of oats and barley and also the quality as measured by the protein content. Fertilizer was applied at various times ranging from planting to as late as 10 weeks after planting. The effect of the fertilizer treatments on the yield and protein content of the grain was determined.

The following conclusions were derived from the experimental results.

1. Nitrogen fertilizer applied at planting generally caused larger yield increases and more total protein per acre than if it was applied later in the growing season.

2. Nitrogen top dressed on oats and barley as late as four to six weeks after planting, when the grain was about six inches tall, caused increases in the yield of grain which were nearly as great as those produced by applying the fertilizer at planting.

3. The yield of oats and barley was not significantly increased by fertilizer applied from four to six weeks after planting if there was not enough rainfall to leach the fertilizer into the root zone in time to benefit the crop.

4. In general, fertilizer containing phosphorus caused larger yield increases if it was incorporated into the soil before planting rather than top dressed after planting.

5. The percent recovery of applied nitrogen by the plants decreased

with the delay in fertilizer application.

6. The 20 pound per acre rate of nitrogen caused a larger increase in yield per pound of added nitrogen than did the 40 pound per acre rate.

7. The experimental evidence regarding the comparison of ammonium nitrate and urea as nitrogen carriers was insufficient to justify any conclusion.

8. Nitrogen fertilizer generally caused increases in the protein content of oats and barley. The protein content of grain where fertilizer was applied in the first half of the growing season was generally the same as when the fertilizer was applied at planting time.

9. The total protein production per acre gradually decreased with the delay of fertilizer application. A marked decline in protein production per acre occurred when nitrogen fertilizer was applied later than six weeks after planting.

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