1952

Effect of Nitrogen and Phosphorus Fertilizers Applied to Crops Grown on South Dakota Soils

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EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZERS APPLIED TO CROPS GROWN ON SOUTH DAKOTA SOILS

By

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

May 1952

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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.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. W. W. Worzella, Head of the Agronomy Department, Dr. Leo F. Puhr, Agronomist, Dr. L. O. Fine, Associate Agronomist, and the Agronomy staff members for their supervision and kind encouragement in conducting this study. Thanks are due the Spencer Chemical Company for providing the fellowship under which this work was conducted.

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INTRODUCTION

The soils of South Dakota are generally very fertile in their virgin condition. Through the years of cropping this fertility has been decreased through crop removal, soil erosion and other factors, until at the present time lack of soil fertility is showing up more and more as a limiting factor in crop production. Inadequate rainfall is often considered the major limiting factor in crop growth in South Dakota. Fertility was thought to be adequate to support maximum production when moisture was plentiful. The development of new crop varieties which possess increased drought resistance and other favorable characteristics and also the continued decline of the soil fertility have made farmers and research men turn to fertilizer and other soil improving practices to insure maximum production in this state.

In view of these conditions this study is concerned with the effects of fertilizers on the growth of small grains in their major production areas in South Dakota. Yields, plant composition, and moisture relations were considered in this study.

A supplementary study was also carried on in the greenhouse and laboratory.

In this work, phosphorus availability and its effects on yield and plant composition was studied on different crops grown in the surface and subsurface of a major South Dakota soil type.

REVIEW OF LITERATURE

Fertility Status of South Dakota Soils

Marbut (4) has reported the soils in the Chernozem belt in their natural condition contain between 0.15 and 0.30 percent nitrogen in the surface layer. The eastern South Dakota soils are determined by Jenny (2) where he has correlated nitrogen content of the soil with annual mean temperature has between 0.2 and 0.25 percent nitrogen in the surface layer. It is generally known that this nitrogen content decreases rapidly when these soils are brought under cultivation. Jenny found that under common farming practices in the Middle West the loss is greatest during the first few years of cultivation and decreases with time until eventually an equilibrium is reached.

Puhr and Worzella (10) have reported in a compilation of work by Puhr and Olson (7, 9) that in 65 years of farming, South Dakota soils have lost 35 percent of their nitrogen content. In the studies on the effects of cultivation on South Dakota soils Puhr and Olson found soils that had lost up to 59 percent of the nitrogen which was contained in the virgin soil.

South Dakota soils are also well supplied with phosphorus. Under common farming practices, however, the available phosphorus is depleted more rapidly than the relatively insoluble phosphorus compounds can be converted to an available form. Puhr and Worzella (10) reported that the total phosphorus supply of South Dakota has decreased 15 percent in 65 years of farming. This, of course, was mainly from the available fraction. Puhr and Olson found decreases up to 38 percent in their studies.

Crop and Fertilizer Relationships

Nelson, Lawton, and Black (5) suggested that new improved varieties which are superior with respect to disease resistance, yield, stiffness of straw and resistance to lodging were capable of giving a greater response to fertilizer than older varieties. In their investigations they found that on Iowa soils oats showed the greater response to nitrogen, but also gave significant increases when fertilized with phosphate fertilizers.

On soils in southeastern Minnesota Toogood and Roost (11) concluded that phosphate was usually the limiting nutrient but that 20 pounds of nitrogen on small grain was beneficial. Nitrogen fertilizers on small grain in their experiment increased the grain response to phosphate fertilizers.

From 1944 to 1946 Puhr and Worzella (10) obtained an average increase in the yield of oats from 46.7 bushels per acre to 56.3 bushels per acre with the use of nitrogen and phosphate fertilizers respectively. When these two elements were combined, 64.8 bushels were produced. Wheat yields were raised from 25.3 bushels per acre to 29.3, 29.5, and 31.3 with additions of nitrogen, phosphate, and a combination of these two elements respectively. In the same report nitrogen and phosphorus fertilized plots yielded 52.6 bushels of barley, while those fertilized with nitrogen and phosphorus alone yielded 45.7 bushels and 44.0 bushels respectively and those with no treatment yielded only 35.4 bushels.

Puhr (8) reported that the 1950 oat yield on the long time plots at the Brookings station where a corn, wheat, oats rotation was followed, was 70.2 bushels of oats where nitrogen and phosphate fertilizers were used.

53.8 bushels of oats per acre were obtained where no fertilizer had been added.

J. T. Pesek (6), in work using P^{32}, found that phosphate fertilization produced significant increases in both percentage of phosphorus contained in the plant and in the dry weight yield.

METHODS AND PROCEDURE

Field Studies

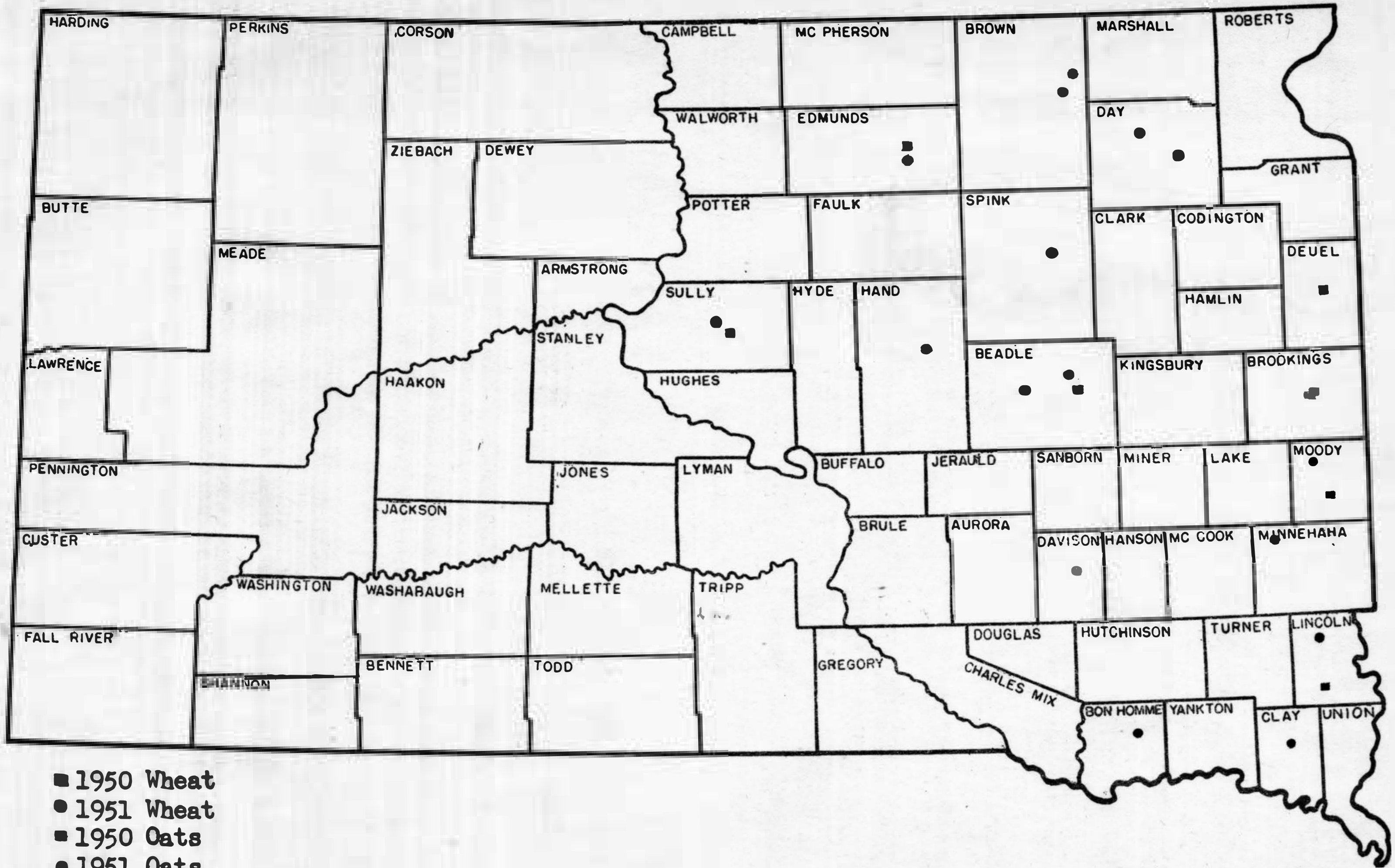
The small grain field experiments were conducted on private farms located in the major production areas of the small grain grown. The accompanying map (Figure 1) shows the general location of all experiments.

The experimental design used was of the randomized block type consisting of four replications and six treatments per replication. The treatments used were check, N_1, P, N_1P, N_2P, and N_3P where N_1, N_2, and N_3 are 20, 40, and 60 pounds of nitrogen added per acre and P is 40 pounds of P_2O_5 per acre. In the 1950 experiments, P is equal to 50 pounds of P_2O_5 per acre. The effects from the different phosphate rate would be negligibly small and therefore no consideration will be given these two rates in further discussion.

The fertilizer was spread on these plots by hand and disked in before seeding. The field plots were seeded and treated as a part of the field that contained them. No special consideration was given to varieties except that all experiments were placed on fields where recommended varieties were grown.

When the grain was ripe, it was harvested by taking three square yards from each plot. The samples were threshed in a nursery threshing machine. Yields were subsequently calculated on a bushel per acre basis.

The grain from four of the wheat experiments was saved for total nitrogen analysis. This was analyzed by the Kjeldahl-Cunning-Arnold method as per A.O.A.C. The nitrogen content as obtained from this analysis was multiplied by a factor of 5.7 to obtain the protein content of the grain.



■ 1950 Wheat
● 1951 Wheat
■ 1950 Oats
● 1951 Oats
■ 1950 Barley
● 1951 Barley

Locations of Field Experiments Conducted in 1950 and 1951

Greenhouse Studies

Greenhouse soil cultures were used which included a surface horizon (0-8 inches) and a subsurface horizon (8-16 inches) of a Kranzburg silt loam soil. Each horizon was treated with four fertility levels, check, 40, 80, and 160 pounds of P_2O_5 in the form of a treble superphosphate fertilizer. The fertilizer constituting the 80 pound level contained radioactive P^{32} which was furnished by the Atomic Energy Commission through the Bureau of Plant Industry. The phosphate fertilizers were thoroughly mixed with the soil in a rotary mixer before soil was placed in pots. Two blanket applications of nitrogen were added at the rate of 50 pounds per acre to eliminate the possibility of this element becoming deficient. Four crops, oats, barley, corn, and buckwheat were grown in each fertility level of the two horizons and arranged in a randomized block design containing four replications and 32 treatments per replication. The pots were rotated periodically during the growth period to eliminate possible effects from differential lighting in the greenhouse. Crops were harvested by cutting them at the soil line. The samples were dried in an oven and the dry weights recorded.

Total phosphorus content was determined in all crops by a slightly modified A.O.A.C. method. The P^{32} content was determined with a Geiger-Muller counter in the plants which were grown in cultures treated with the radioactive element. The "A" value of Fried and Dean (1) was then calculated for each crop on each of the two soil horizons.

EXPERIMENTAL RESULTS AND DISCUSSION

Field Studies

Effect of Fertilizer on the Yield of Wheat

The yield results of the 1950 and 1951 wheat experiments are recorded in Tables 1 and 2 respectively. An analysis of variance was run on the results of all experiments and the F values and least significant differences are included in the tables. The yields are also plotted graphically in Figures 2 and 3. Due to adverse conditions such as hail and weeds, the grain from only four experiments was harvested in 1950. In this year only the Edmunds County experiment proved statistically significant although the fertilized treatments gave some increase over the checks in all experiments. It is seen in the table that nitrogen was the major limiting element in the Beadle, Sully, and Edmunds County experiments. In these three experiments phosphate, when used alone, decreased the yields from those where no fertilizer was used. In the Edmunds and Beadle County experiments application of phosphate increased the efficiency of the nitrogen fertilizer. The Deuel County experiment shows that phosphorus is the limiting element. This experiment however was located in the extreme eastern part of the state which is removed from the spring wheat belt.

The 1951 wheat experiments were placed in Day, Edmunds, Spink, Hand, Sully, and two in each of Beadle and Brown Counties. (Where two experiments were placed in one county they will be designated by an A and B). Of these the Beadle (A) experiment was the only one in which the F value was not significant. In this experiment phosphorus alone gave an increased yield of nearly four bushels while nitrogen alone decreased the

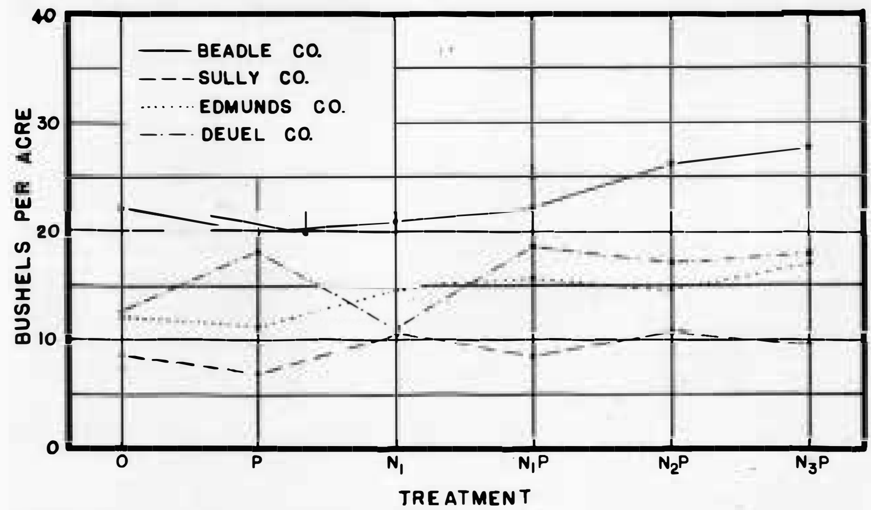


Figure 2. Effect of Fertilizer Treatments on Yield of Wheat in 1950.

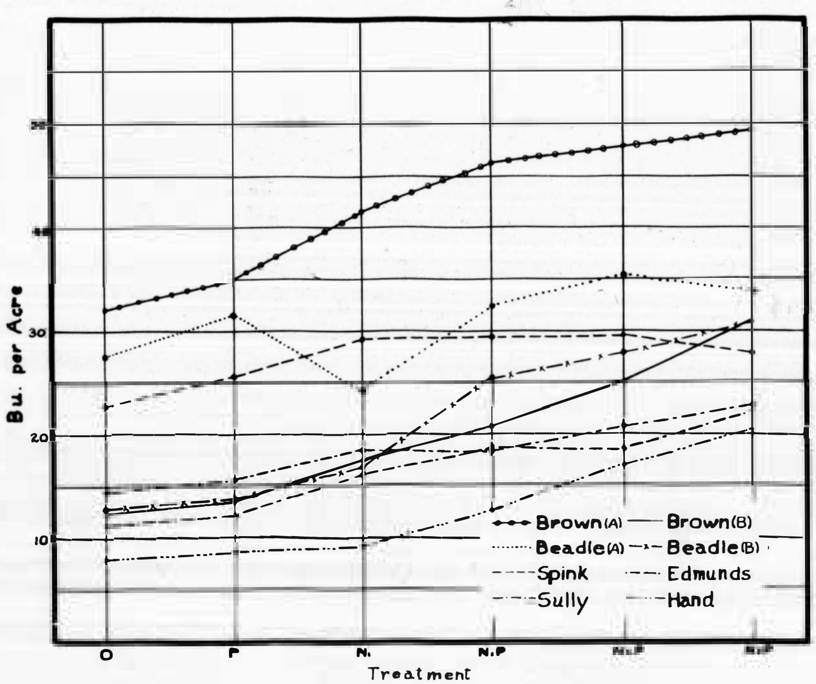


Figure 3. Effect of Fertilizer Treatments on Yield of Wheat in 1951.

yield from the check three bushels per acre. Combinations of these elements gave slightly higher yields than either one alone. In all other experiments phosphate alone gave minor increases while application of nitrogen resulted in an average yield increase of about four bushels per acre. It is noted in Table 2 and Figure 3 that the largest yields were obtained from the use of nitrogen and phosphate fertiliser together and were generally increased proportionally with the rate of nitrogen added. Differences such as are seen in Plate 1 were generally visible in the 1951 wheat experiments.

Table 1. Yield Results of 1950 Wheat Fertility Experiments

Treatment	Beadle Co.	Edmunds Co.	Sully Co.	Deuel Co.
	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre
Check	21.9	12.2	8.7	12.7
P	19.8	11.2	7.0	18.2
N_1	21.6	14.5	11.0	11.4
N_1P	22.3	15.6	8.7	18.5
N_2P	26.5	14.6	10.5	17.0
N_3P	27.6	16.5	9.8	17.5
F value*	1.2	11.6	2.1	2.3
L.S.D.**		1.7		

* Significant at 5% level: 2.90
** Least significant difference at 5% level

Table 2. Yield Results of 1951 Wheat Fertility Experiments

Treatment	Beadle(B)	Beadle(A)	Brown(B)	Brown(A)	Day	Edmunds	Hand	Spink	Sully
	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre
Check	12.7	27.6	12.5	32.1	36.2	11.5	7.8	22.7	14.4
N_1	17.5	24.6	17.7	41.3	38.1	16.8	9.3	29.1	18.4
P	14.2	31.4	14.0	35.0	36.2	12.5	8.3	25.8	15.8
N_1P	25.6	32.4	20.9	46.7	40.9	18.4	12.5	29.6	18.1
N_2P	27.9	35.2	25.3	44.0	43.0	18.7	17.4	29.6	21.0
N_3P	31.5	33.8	31.0	52.1	39.2	22.9	20.8	27.8	23.2
F value*	19.8	2.4	32.5	10.2	4.1	7.2	18.7	3.4	6.6
L.S.D.**	5.3		3.7	7.1	4.0	4.8	3.2	4.5	3.8

* Significant at 5% level: 2.90

** Least significant difference at 5% level

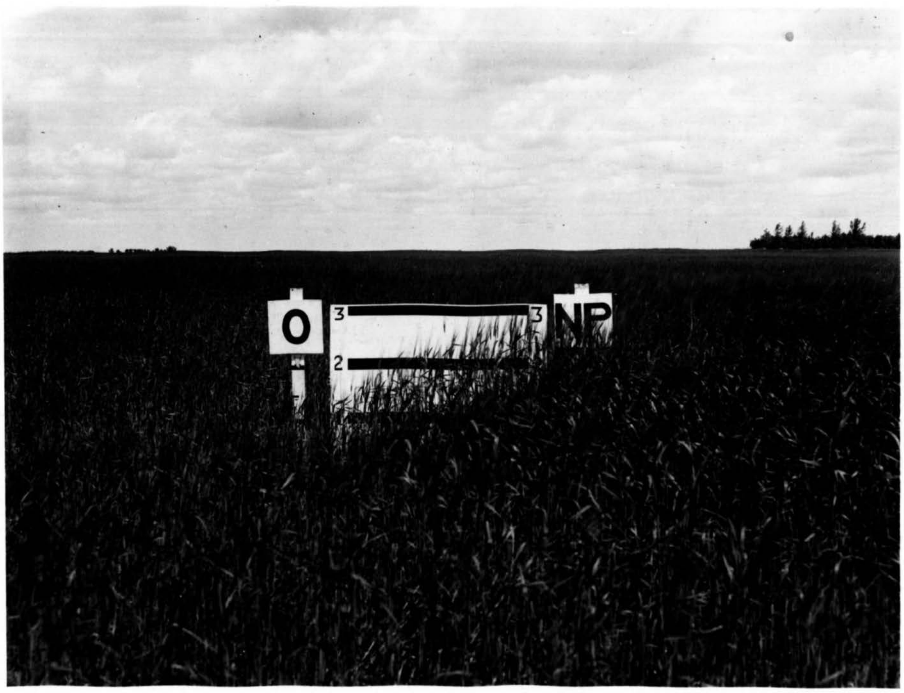


Plate 1. Typical view of differences in growth of wheat in 1951 wheat fertility experiments.

Fertility and Moisture Relationships in Wheat Production

It can be seen in Figures 2 and 3 that the yield increases in 1950 are small and insignificant as compared to those in the 1951 experiments. One explanation for this could be the comparatively dry 1950 season. Although the precipitation in May and July of 1950 was slightly above normal, June was the third driest on record.

It is interesting to note in Figures 2 and 3 that the check yields in 1950 and 1951 are grouped in approximately the same range. This suggests that moisture above a point is not the limiting factor in wheat yields in South Dakota since moisture conditions in the wheat belt were very different in the 1950 and 1951 seasons. This means that on most soils on which experiments in the wheat belt were conducted, maximum yields cannot be obtained under the present fertility conditions though optimum climatic conditions prevail. Where abundant moisture was present during the growing season maximum yields were realized only with increased fertility.

In an attempt to correlate yields and yield increases with fertility and moisture relationships, the total precipitation from the four month period of April through July was obtained from the weather station nearest the individual experiments.

In Figure 4 the check yields, including both the 1950 and 1951 wheat experiments, are plotted against the four month precipitation. In Figure 5 the yields from the N_2P fertility level are used. It is shown here that there is a significant correlation between precipitation for the four month period and the yields at the N_2P level of fertility (a correlation coefficient of .532 is significant at the 5 percent level). The

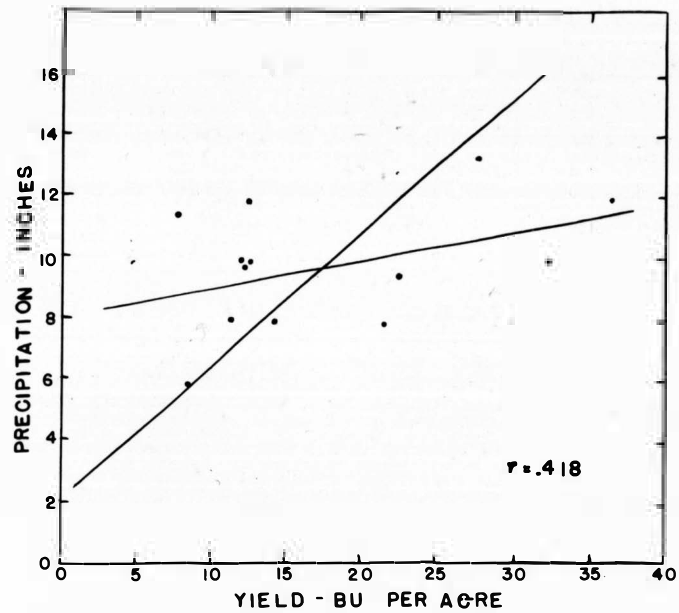


Figure 4. Effect of April, May, June, and July precipitation on the yield of wheat grown on the check plots of 1950 and 1951 wheat fertility experiments.

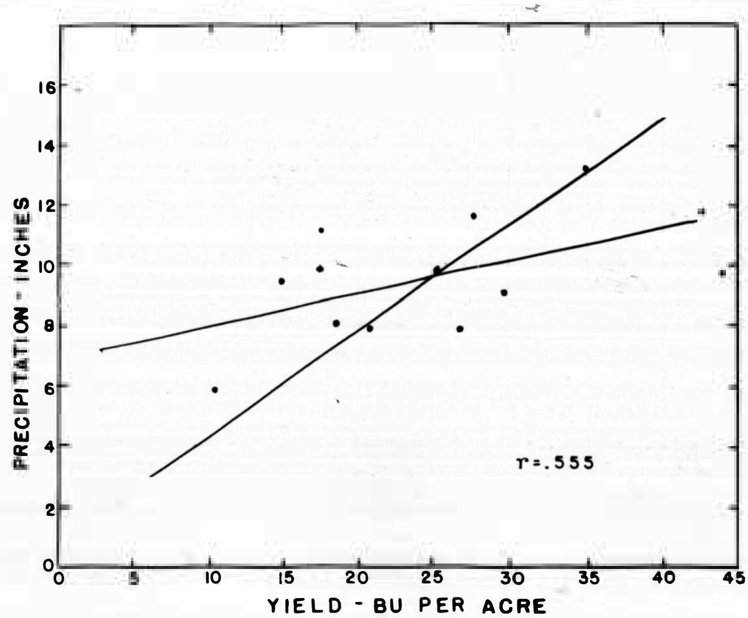


Figure 5. Effect of April, May, June, and July precipitation on wheat grown at the N_2P level of fertility in 1950 and 1951.

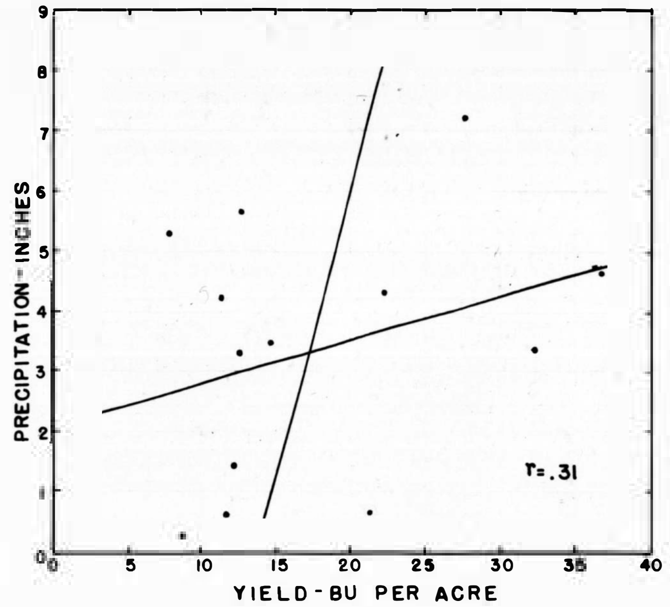


Figure 6. Effect of June precipitation on the yield of wheat grown on check plots of 1950 and 1951 wheat experiments.

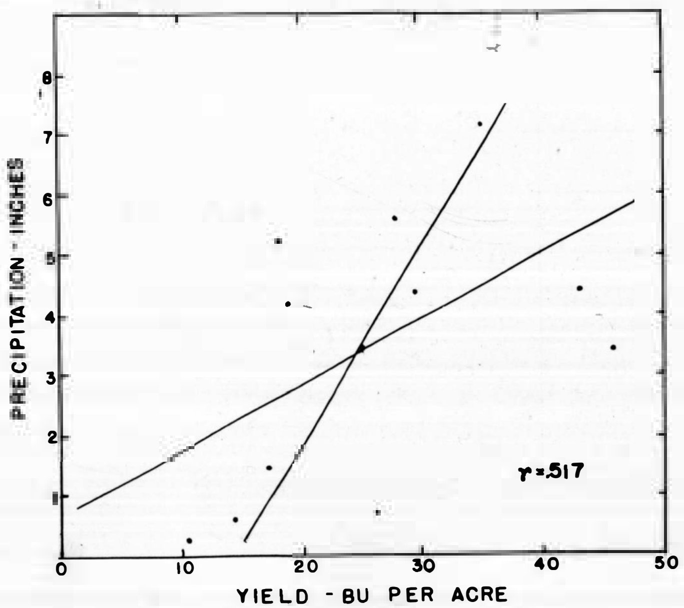


Figure 7. Effect of June precipitation on the yield of wheat grown at the N_2P level of fertility in 1950 and 1951.

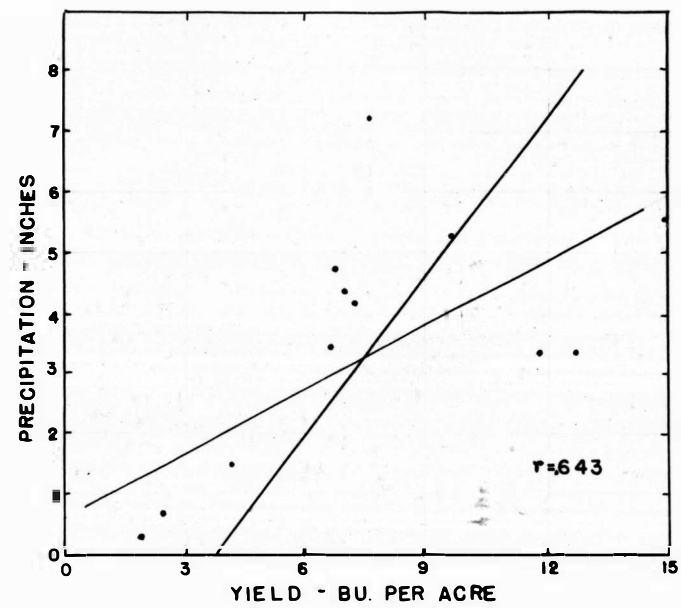


Figure 8. Effect of June precipitation on the yield increases of wheat grown at the N_2P level of fertility over that grown on check plots in 1950 and 1951.

correlation coefficient of the check yields did not prove significant at the 5 percent level. In the growth of wheat June is probably the critical month for supplying moisture to wheat since June is the month in which most of the growth and head formation takes place. For this reason correlations have been run between precipitation in June and the check yields, yield at the N_2P level of fertility, and the bushels per acre increase at the N_2P level over the check yields (Figures 6, 7, 8). As is seen in Figure 6 there was very little correlation between the check yields and rainfall in the 1950 and 1951 seasons. Where June precipitation was used in the correlations (Figures 6, 7, 8) there are even more marked differences in the correlation coefficients showing that the June rainfall was more critical at a high fertility level.

Effects of Fertilizer on the Protein Content of Wheat

The experiments selected for protein analysis were from Spink, Brown (A), and two from Beadle County. The average protein contents and F values are recorded in Table 3.

Table 3. Percent of Protein in Wheat When Grown at Various Fertility Levels.

Treatment	Beadle(A)	Beadle(B)	Brown(A)	Spink
	Percent	Percent	Percent	Percent
Check	15.8	13.9	12.5	13.1
N_1	16.0	14.3	13.9	13.8
P	15.5	13.9	13.2	13.3
N_1P	15.3	13.1	13.2	13.1
N_2P	15.5	13.9	12.7	14.3
N_3P	16.1	14.2	13.2	14.5
F Values*	2.0	1.5	2.3	3.8

* Significant at 5% level: 2.90

Although some increases in the percent of protein in the wheat from all counties were obtained the differences in the Spink County samples were the only ones which proved statistically significant. The largest increases seem to be gotten in these experiments from the wheat grown on plots where the available nitrogen is high in relation to the phosphorus. Comparisons between counties cannot be drawn since the same variety of wheat was not used on all experiments.

Effect of Fertilizer on the Yield of Oats

Oats fertility experiments were maintained in 1950 and 1951 and treated identically to the wheat. The yield results were analyzed statistically. The average yields, F values and the least significant differences are recorded for the 1950 and 1951 experiments in Tables 4 and 5 respectively. Yields with respect to treatments are shown graphically in Figures 9 and 10.

Table 4. Yield Results of 1950 Oat Experiments at Various Treatments.

Treatment	Lincoln(A)	Lincoln(B)	Moody
	Bu/Acre	Bu/Acre	Bu/Acre
Check	53.5	53.8	42.6
N_1	59.6	63.6	45.4
P	58.8	55.1	43.3
N_1P	72.2	77.5	42.3
N_2P	74.8	97.2	47.0
N_3P	78.2	86.4	44.7
F value*	9.6	23.5	0.3
L.S.D.**	9.8	11.1	11.0

* Significant at 5% level: 2.9
** Least significant difference at 5% level

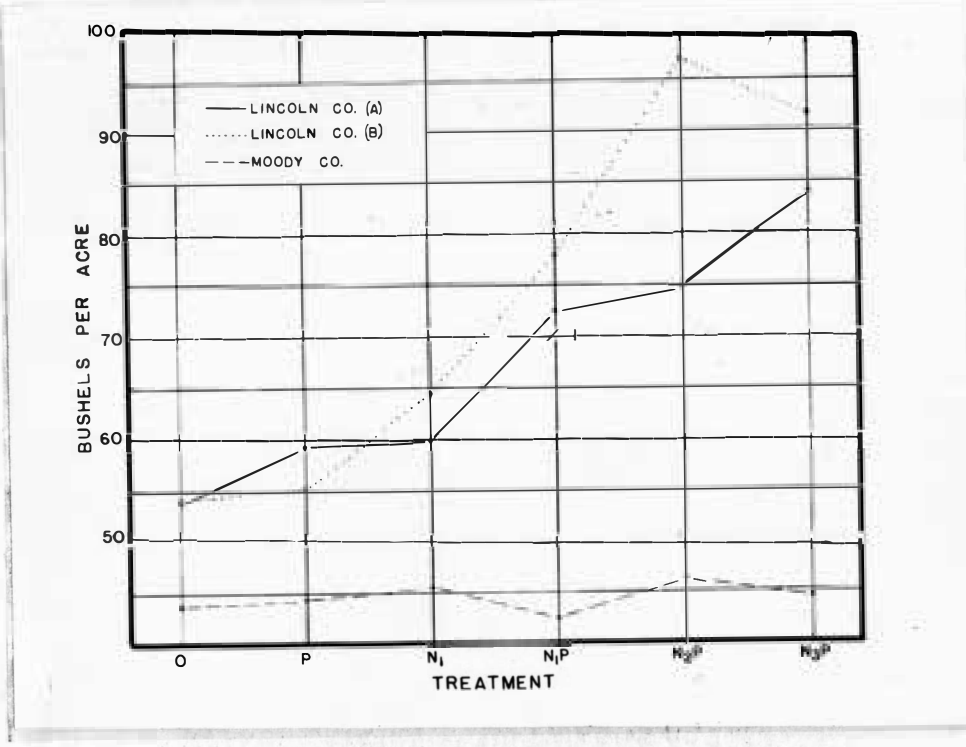


Figure 9. Effect of fertilizer treatments on yield of oats in 1950.

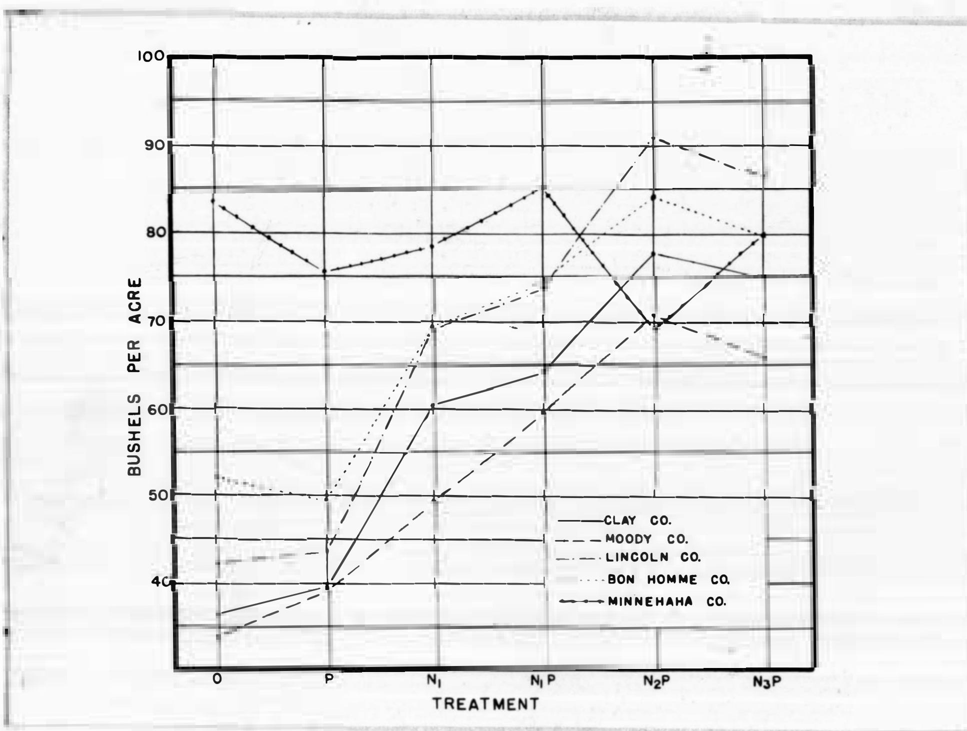


Figure 10. Effect of fertilizer treatments on yield of oats in 1951.

Table 5. Yield Results of 1951 Oat Experiments at Various Treatments.

Treatment	Bon Homme	Clay	Lincoln	Minnehaha	Moody
	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre	Bu/Acre
Check	52.5	36.7	42.3	82.7	33.3
N_1	68.6	69.4	69.0	78.2	49.8
P	49.1	39.7	43.3	75.8	39.8
N_1P	74.2	64.0	73.3	85.5	59.2
N_2P	84.0	77.5	91.7	69.5	71.7
N_3P	80.0	69.7	86.7	79.1	66.0
F value*	7.6	8.7	28.4	0.9	16.2
L.S.D.**	15.8	17.4	11.9		11.2

* Significant at 5% level: 2.90
** Least significant difference at 5% level

In 1950 oat experiments were placed in Moody County and two in Lincoln County. In the Lincoln County experiments highest yields were obtained when the nitrogen and phosphate fertilizer were used in combination although increases in yield over the check were had on plots where nitrogen and phosphorus were used separately. No significant differences in yield were found in the Moody County plots.

In 1951 except for the Minnehaha County experiment significant increases were obtained with the use of 20 pounds of nitrogen. Slightly higher yields resulted when phosphorus was added, especially when used with the 40-pound rate of nitrogen. The 60-pound rate of nitrogen decreased the yields of the grain on these plots which was a result of severe lodging when this high rate of nitrogen was applied. The erratic results of the Minnehaha experiment were also probably due to the lodging of the grain which was very severe on all treatments.

Effect of Fertilizer on the Yield of Barley

Barley experiments were also handled identically to the wheat and oat experiments. Two barley experiments were run during the summer of 1950 and one in 1951. The average yields of all treatments for the two years are given in Table 6 along with the F values and least significant differences.

Table 6. Yield Results of Barley at Various Fertility Treatments.

Treatment	1950 Brookings(A)	1950 Brookings(B)	1951 Davison
	Bu/Acre	Bu/Acre	Bu/Acre
Check	36.6	33.7	28.0
N_1	35.9	38.9	35.7
P	44.0	43.9	28.4
N_1P	45.2	51.9	44.8
N_2P	55.1	53.4	50.6
N_3P	45.9	62.2	53.8
F value*	1.9	16.2	8.5
L.S.D.**		7.9	11.6

* Significant at 5% level: 2.90
** Least significant difference at 5% level

In 1950 one of the two experiments showed significant responses in yield differences. Though differences were found in the Brookings (A) experiment the variable data caused the F value to be small. In both 1950 experiments phosphorus gave large increases. Nitrogen alone resulted in some increase in the Brookings (B) experiment. Highest yields were obtained when both elements were used in combination however.

In the 1951 Davison County experiment nitrogen was the major limiting element. Phosphorus gave no increase when used alone but when used with nitrogen it increased the efficiency of the nitrogen.

Greenhouse Studies

Photographs of the four crops as seen growing at the time of harvest are shown in Plates 2, 3, 4, and 5. It can be readily seen that the plants responded greatly to additions of phosphate fertilizer in both horizons and showed a variable growth where no fertilizer was added.

Increases in growth from fertilizer treatment on the two horizons can be seen in Figure 11 where the yield in grams of dry material is plotted graphically against the phosphate treatment on the oats, barley, and corn. Yield was not shown for the buckwheat because of the

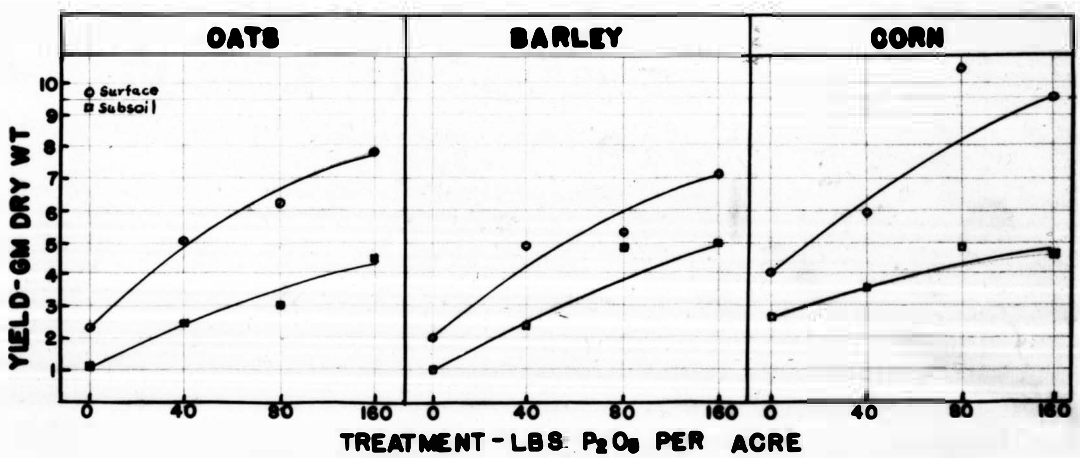


Figure 11. Yield of Different Crops Grown on Surface and Subsurface Soils as Influenced by Various Rates of Phosphate Fertilizer Applications.

variable stand which resulted from poor germination of the seed. Added phosphate gave generally substantial yield increases, the highest yields being obtained from the highest applications of the fertilizer. There

Plate 2. Oat plants grown in greenhouse culture of surface and subsurface soils fertilized with 80 pounds of P_2O_5 and checks.

Plate 3. Barley plants grown in greenhouse culture of surface and subsurface soils fertilized with 80 pounds of P_2O_5 and checks.

Plate 4. Corn plants grown in greenhouse culture of surface and subsurface soils fertilized with 80 pounds of P_2O_5 and checks.

Plate 5. Buckwheat plants grown in greenhouse culture of surface and subsurface soils fertilized with 80 pounds of P_2O_5 and checks.

are seemingly erratic results from the 80-pound treatment. One explanation for this may be in the physical condition of the fertilizer which was used in this treatment. The P^{32} material was not ground as finely as that in the other treatments. J. T. Pesek (5) found that more finely ground material was more effective in supplying phosphorus to oats. The surface soils supported higher yields in all treatments although the phosphated subsurface soils gave substantially higher yields than did the untreated surface soils. The curves representing the subsurface soils level off more than surface soil curves at high rates of phosphate application suggesting that another factor may be limiting in the lower horizon.

In Figure 12 the percentage of phosphorus in the dry tissue is plotted against the phosphate treatments. A general increase in the

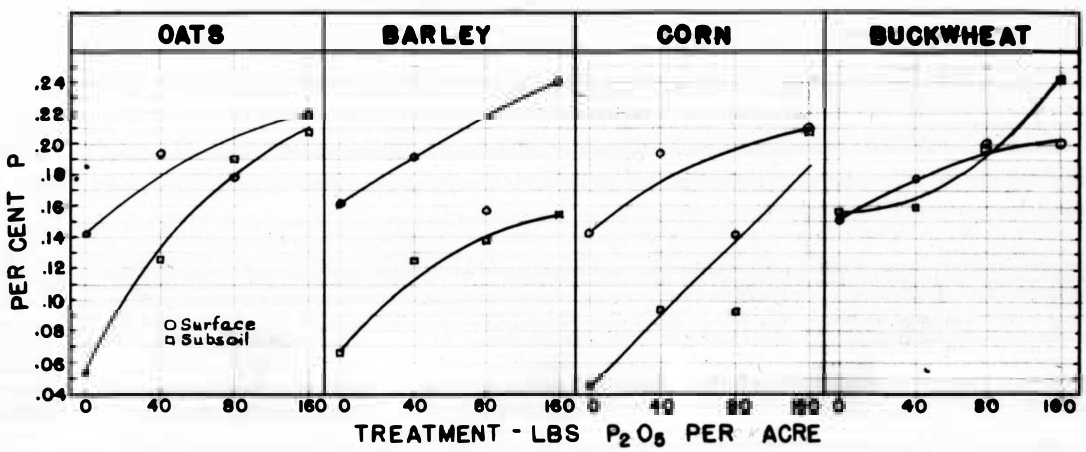


Figure 12. Phosphorus Content of Different Crops Grown in Surface and Subsurface Soil as Influenced by Various Rates of Phosphate Applications.

percentage of phosphorus is shown with increased rates of phosphate application. In the oats and corn curves, there seems to be a leveling off of the curves at coincident points, indicating that a maximum in the phosphorus content of the plant that can be produced with applications of phosphate has been reached.

Figure 13 is a graphic representation of the relation between yield and phosphorus content. In all cases increased yields are positively correlated with increased phosphorus content. This could be

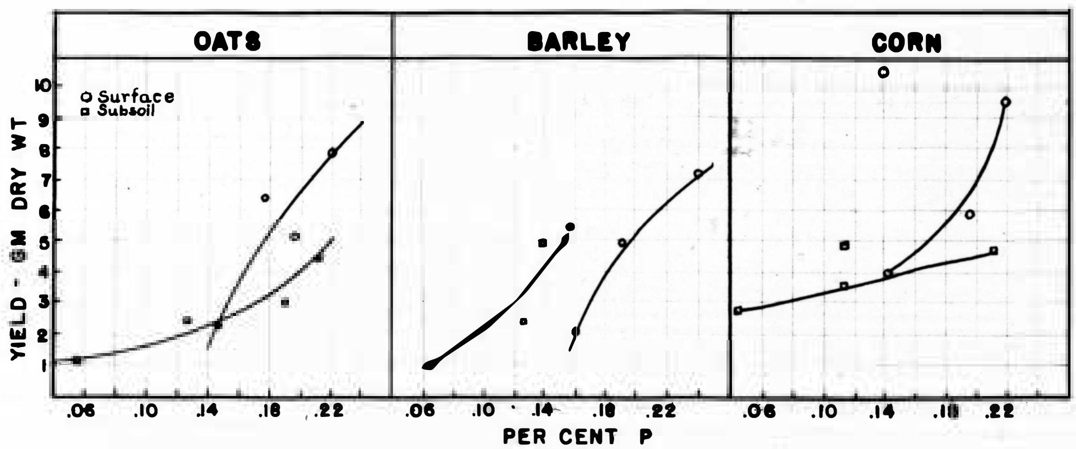


Figure 13. Curves Showing Relations of Yield and Phosphorus Content of Various Crops Grown on Surface and Subsurface Soils.

expected from the previous results. In general the curves of the surface soil are steeper than for the subsurface soil which suggests again that effects from another limiting factor is entering into the experiment.

Maurice Fried and L. A. Dean (1) formulated an "A" value which is a measure of the amount of an available nutrient present in the soil. They give the proportion $A_{soil}/B_{soil} = A_{plant}/B_{plant}$ where A_{soil} is the amount of an available nutrient in the soil, B_{soil} is the amount of available nutrient added to the soil in a standard, A_{plant} the amount of the nutrient in the plant derived from the soil, and B_{plant} the amount of nutrient in the plant derived from the standard. With the use of a radioactive standard which in this experiment was P^{32} the B_{plant} factor can be determined and therefore the A_{plant} factor can be found by subtraction. The standard added (B_{soil}) is known and the remaining A_{soil} factor can be calculated. This is denoted as the "A" value. The average "A" values for the four crops are given in Table 7. These data were very erratic in this part of the experiment and these "A" values given cannot be taken as exact values. The value for the oats seems to agree the best with the data discussed previously which indicated that the surface soil was more abundantly supplied with available phosphorus. The values for the buckwheat would be expected to be more nearly the same than for the other crops since smaller differences were observed in their growth in the check cultures. The "A" values for the corn do not agree with the yield data and cannot be explained.

Table 7. "A" values for Various Crops on Two Horizons of Soil.

Crop	Surface Soil	Subsurface Soil
	Lbs. P/Acre	Lbs. P/Acre
Oats	44	24
Barley	36	32
Corn	97	121
Buckwheat	39	39

SUMMARY AND CONCLUSIONS

Several small grain fertility experiments were conducted throughout the eastern half of South Dakota. These were conducted on wheat, oats, and barley and were fertilized with various rates of nitrogen and phosphate fertilizer. It was found that there was a general response to both elements, highest yields being obtained with the use of a combination of the nitrogen and phosphate fertilizers in most cases. Nitrogen was more generally lacking than phosphate, however. In the wheat belt increases in yield on fertilized plots were found to correlate quite closely with the rainfall during the growing season. Highest protein gains in wheat were obtained where the available nitrogen was high in relation to the phosphorus.

In the supplementary greenhouse studies oats, barley, corn, and buckwheat were grown on a surface and subsurface horizon of a major soil type in eastern South Dakota. These soils were phosphated with three rates of phosphorus 40, 80, and 160 pounds of P_2O_5 per acre. The 80-pound rate contained radioactive P^{32} which was used to calculate the percent of phosphorus in the plant that came from the fertilizer and subsequently to calculate the "A" value, a measure of the available nutrient in the soil. Both the surface and subsurface horizons were found to be lacking in available phosphorus, the subsurface extremely so. A very high response to phosphate fertilizers was obtained on the small grain and corn and to a lesser extent on the buckwheat. Under greenhouse conditions the threshold of the growth curve was not reached on either horizon with the application of 160 pounds of P_2O_5 per acre. The percentage of phosphorus in the plants was increased with increased available phosphorus in the soil. Highest yields were obtained where a comparatively high percentage of phosphorus was present in the plant.

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