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Soil Investigations.

1. Fertilizer Tests with Wheat and Corn.
2. The Loss of Nitrogen from Soils.

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FERTILIZER TESTS WITH WHEAT AND CORN.

HARRY SNYDER.

Frequent inquiries have been received at the Experiment Station in regard to the use in this state of commercial fertilizers for increasing the yield of crops. It was deemed that the question was of enough importance to warrant undertaking investigations to determine the extent to which applications of the various plant food elements in commercial forms would increase the yield and quality of wheat and corn. On account of the limited funds available, the tests that have been made and are reported in this bulletin are largely preliminary to further investigation along this line.

The general plan of the investigation was to apply nitrogen, phosphoric acid and potash fertilizers, singly and in combination, to quarter acre plots of wheat, with the object of determining the influence of these fertilizers upon the character of growth and upon the yield. A number of former students of the School of Agriculture co-operated in this work, and also some others who are interested in questions of fertility.

In some localities a serious difficulty experienced in the growing of wheat has been the heavy growth of straw and the failure of the grain to properly fill. It was hoped that some data might be secured from these experiments as to the cause of this unbalanced development of the wheat plant.

The Experiment Station supplied the fertilizers, while those who co-operated in the work furnished the necessary labor, and in many cases bore the additional expense of having the grain from the plots separately threshed. The tests included a variety of soils, but principally those that

had been under long cultivation and were in a comparatively low state of productiveness.

Similar experiments were made about fifteen years ago, and it was then found that commercial fertilizers gave but little increase in the yield of grains on the various soil types of the state. As most of the soils at that time were comparatively new, the use of commercial fertilizers failed to make any appreciable returns in crop yields. Since the decline in yield has been more noticeable during the past fifteen years, it was believed that the time had arrived when the tests could be profitably repeated.

For the experiments with wheat, five quarter acre plots were selected; a complete fertilizer was used on one plot, and one plot was left unfertilized, while to each of the remaining three plots either nitrogen, phosphoric acid or potash alone was applied. 150 lbs. of a complete fertilizer, containing 1.68 per cent of nitrogen, 15.46 per cent of phosphoric acid and 1.9 per cent of potash, was used on the first plot. This was purchased as containing 2 per cent of ammonia, 2 per cent of potash, and 12 per cent of phosphoric acid. The 2 per cent of ammonia is equivalent to 1.66 per cent of nitrogen. Of the total phosphoric acid, 1.35 per cent was in water soluble form and 9.25 per cent was citrate soluble, making a total of 10.6 available phosphoric acid. It will be observed that, compared with the guaranty, the goods were slightly deficient in potash and phosphoric acid. It was not a complete fertilizer of high degree of concentration of the plant food elements, but one which supplied the nitrogen and potash rather in medium amounts, and the phosphoric acid in liberal amount.

On Plot No. 2, 80 lbs. of treated rock phosphate, containing 17.56 per cent of total phosphoric acid, was used.

1. Complete Fertilizer.	2. Phosphate Fertilizer.	3. Potash Fertilizer.	4. Nitrogen Fertilizer.	5. No Fertilizer.

Diagram of Fertilizer Plots.—Size ¼ acre each.

To Plot No. 3, 40 lbs. of kainit, containing 13.5 per cent of potash, was applied, and to Plot No. 4, 40 lbs. of nitrate of soda, containing 15.06 per cent of nitrogen.

At the time these fertilizers were sent out, they were quoted on the St. Paul market as follows: Complete fertilizer $25.00 per ton, acid phosphate $15.00 per ton, and nitrate of soda $50.00 per ton. Directions for applying the fertilizers were sent to each one who took part in the work. The fertilizers were spread broadcast about the time of seeding. In some cases they were applied with a drill by cross drilling after seeding. That the plots might be kept distinct, suitable labels for marking the corner stakes were supplied.

Experiments with Wheat at London, Freeborn County.

These experiments were carried on under the supervision of Prof. William Robertson, of the School of Agricutlure. The tests were made on land which had recently come into the possession of Prof. Robertson and was adjacent to his farm. The soil had been continuously cropped for about thirty-five years and had probably never received an application of fertilizer in any form.

It was originally soil of high productiveness, but, because of exclusive grain cultivation, it had been reduced to a very low condition as to fertility. Prof. Robertson stated that it was probably the poorest piece of land in the county.

The land was fall plowed, and was seeded April 15th, the fertilizer being applied a little later with a shoe drill, except the phosphate, which was applied broadcast

because of its failing to work well with the drill. On May 10th, 13th and 14th, there were exceptionally heavy showers, and the wet weather continued until the 5th of July, after which there was no more rain until the crop had been harvested. Prof. Robertson reported that the grain on the plots receiving the complete fertilizer and the dressing of nitrogen was noticeably taller and of a darker green than on the other plots, and that at time of harvest the grain on plot 4, the one receiving nitrogen, was about eight inches taller than that on plot 5, which received no fertilizer, the differences in height and color forming a dividing line between the two plots which was distinct from end to end. Plot No. 3, receiving the potash fertilizer, was slightly lower ground than the other plots; otherwise the plots were of uniform character. On August 23rd all of the wheat was threshed from the shock and the following yields were obtained:

	Kind of Fertilizer	Yield of Plot lbs.	Yield per Acre. bu.
Plot 1	Complete,	163	10.8
Plot 2	Phosphate,	108	7.2
Plot 3	Potash,	147	9.8
Plot 4	Nitrogen.	153	10.2
Plot 5	None,	110	7.3

It is to be noted that the yields from all of the plots were low, and that the addition of the nitrogen fertilizer increased the yield about three bushels per acre, while the application of phosphate fertilizer had no effect whatever upon the yield. On this soil, where grain had been grown for many years, until its crop producing power was reduced to about 7 bushels per acre, the addition of commercial fertilizers in the medium amounts used in this experiment, did not materially increase the yield of the crop. The 150 lbs. of complete fertilizer, costing $1.88, produced an increase of 53 lbs. of wheat, which was sold for 90

cents per bushel, making a loss from the use of the fertilizer of over $1.00 per plot. In the case of the nitrogen fertilizer, the 40 lbs. of nitrate, costing $1.00, produced an increase of 43 lbs. per plot, making a loss of about 60 cents per plot from its use. Had the fertilizer been used in larger amounts than 600 lbs. per acre, it is possible that larger yields might have been secured. From the results obtained, it is safe to conclude that there will be no farther increase in yields the second year from residual action of the fertilizer, because nitrogen was the only element that appreciably affected the yields, and the results from the application of the nitrogen in these fertilizers are all secured the first year.

In brief, it can be said that the commercial fertilizers did not sufficiently increase the yield to pay for the fertilizers applied, and that the yield was not increased to the same extent as on adjoining lands that were manured with farm manures and upon which a rotation of crops had been practiced. On farms in Freeborn County, where live stock is kept and a good system of farming is practiced, 25 bushels and more of spring wheat per acre are often secured.

It is quite evident that it is not possible on an old, run down farm to secure a large yield of wheat by means of one application of commercial fertilizer. Maximum yields at minimum cost are secured only through other methods of treatment, in which perhaps commercial fertilizers may form an essential part.

Analyses of the wheat grown on these plots showed an improvement in the nitrogen content of the grain from the plots receiving the complete and the nitrogenous fertilizers. The grain from the plots which received the phosphate fertilizer contained 9.27 per cent of protein; that from the plot receiving the potash fertilizer 9.71 per cent; from the plot to which no fertilizer was applied 10.16; from the one with the complete fertilizer 11.7; while the wheat from the plot receiving the nitrogen fer-

tilizer contained 12.1 per cent. The application of the nitrogen increased the proteid content of the grain about 2 per cent. The effects upon the milling and bread-making qualities of the wheat receiving the nitrogenous and other fertilizers will be discussed in a future bulletin.

On the farm of Mr. A. W. Trow, of Glenville, in the same county, similar experiments were made with oats. On July 24th Mr. Trow reported that he did not find any great difference in the growth of the crops on the plots receiving the different fertilizers. "However, the plot receiving the application of potash seemed to be producing straw that was a trifle more stiff than the others, and the plot to which the complete fertilizer was applied showed a somewhat heavier growth than on the adjoining ground that received no fertilizer." At the time of harvest the difference in the appearance of the crop was so slight that Mr. Trow did not consider the results sufficiently promising to warrant the crop being separately harvested and threshed. On Mr. Trow's farm clover had been grown, live stock kept and the manure applied regularly and systematically to the soil, and under such conditions the application of commercial fertilizers did not appreciably influence the production of the oat crop.

The extreme conditions under which the fertilizers were used on these two farms show that on land reduced by continuous cropping the increased yields from commercial fertilizers are not to be compared with those secured on land where a high state of fertility has been secured by systematic treatment, as the use of farm manure, the production of clover and the rotation of crops. On farms where only a scant amount of manure is produced and where the land is in a medium state of fertility, it is possible that better showings would have been obtained from the use of the commercial fertilizers than was the case on these two farms.

On old grain land it is especially noticeable that the loss of nitrogen and humus, due to continuous cultiva-

tion, has been one of the chief factors in the decline in crop producing power of the soil. This loss of nitrogen through the decay of the humus and no renewal of the humus-forming materials has been pointed out and discussed in former bulletins of this station, particularly Bulletins Nos. 30, 41, 53, 65 and 89. It is to be noted in connection with the loss of nitrogen and humus from the soil that these field tests give identically the same results as were secured in the laboratory from the analysis of soils.

Tests at the Experiment Station Farm.

In co-operation with Prof. Andrew Bons, of the Division of Agriculture, experiments were undertaken at the University Farm. Owing to the over-crowded condition of this farm and the lack of available land, soils especially suitable for the purpose were not available. The soil allotted was in a fair state of fertility, but the plots were not in all respects as even as could have been desired for experimental purposes. The grain was seeded April 25th at the rate of 1¼ bushels per acre, and was ripe and ready for harvesting August 12th. The amounts of fertilizers applied per acre were the same as in the experiments just described. The results secured are given in the following table:

Fertiiizer.	Amount per Plot	Amount per Acre	Yield per Plot		Yield per Acre	
			Straw	Grain	Straw	Grain
	lbs.	lbs.				Bu.
Phosphate	80	320	1378	402	5472	26 8
Nitrogen	40	160	1711	439	6844	29.25
None	0	0	1236	434	4944	28 8
Potash	40	160	1125	360	4500	24.
Complete	150	600	1075	360	4300	24.

It is to be noted that the application of the 40 lbs. of nitrate of soda resulted in a gain of 5 lbs. of wheat, equiv-

alent to one-third of a bushel per acre. The other fertilizers failed to produce any increase in yield. In fact, the check plot, or the plot receiving no fertilizer, gave a larger yield per acre than the plots receiving either potash, phosphate or the complete fertilizer. In the complete fertilizer, the nitrogen was in the form of tankage which, because of the slower action of nitrogen in this form, may perhaps account for the failure to give results. A large increase in the weight of straw was secured from the application of the nitrogen, there being nearly a ton more per acre than from the check plot. The fact that lower yields were secured on all the plots, except the one receiving nitrogen, while no increase was secured from the complete fertilizer, is unusual, and there is no apparent reason why a slight decline should have followed the application of the potash and phosphate fertilizers. It is possible that during coming years they may result in increasing the yields.

It is evident that, with a soil in such condition as that used for these experiments at the Experiment Station Farm, commercial fertilizers are not economical. On this land producing 27 bushels of wheat per acre any additional increase does not appear to have been secured from the use of mineral fertilizers, and the application of nitrogen was not economical, as it resulted in an increase of only about one-third of a bushel per acre.

Experiments at Benson, Swift County.

These experiments were made on the farm of Dean W. M. Liggett, under the supervision of Mr. Alec. Boss, foreman. The land was of an entirely different character from that used at the Experiment Station or in Freeborn County, where the experiments previously recorded were made. The land was in a fair state of fertility and had, a few years previously, produced a good crop of clover, and was a type of soil which gave "a rank growth of straw

though in some instances the wheat failed to fill and ripen normally." The wheat was sown about April 1st, and the fertilizers were applied a few days later in the same amounts as previously given. The plots were harvested and threshed separately. The plot receiving the complete fertilizer produced 151 sheaves of wheat; the plot fertilized with phosphates alone 148; the plot fertilized with nitrogen 128, and the one without fertilizer 125. Mr. Boss reported at the time of harvest that the plot receiving the potash fertilizer produced wheat with strong straw, of excellent color and apparently well filled. The plot receiving the nitrogen did not ripen quite as rapidly as the other plots. The following yields per acre were secured from the different plots:

Plot No.	Kind of Fertilizer	Yield per Plot	Yield per Acre
1	Complete,	6 bu.	24 bu.
2	Phosphate,	5 bu.	20 bu.
3	Potash,	5 bu.	20 bu.
4	Nitrogen,	4 bu.	16 bu.
5	None,	4 bu.	16 bu.

On this farm, where clover had been grown, nitrogen alone failed to show any beneficial results, but the phosphoric acid and potash fertilizers each gave an increase of four bushels per acre, while the complete fertilizer, in which these two elements were both present, caused a further increase of four bushels. Thus the joint use of potash and phosphoric acid resulted in an increase of eight bushels per acre, while the use of each singly gave an increase of only four bushels. In the case of the complete fertilizer, the nitrogen was supplied at a loss. The eight bushels of wheat were secured from the use of 600 pounds of complete fertilizer, costing $7.50 per acre. At the time of harvest this increase in yield was just about sufficient to pay for the fertilizer used. In the case of the phosphate

fertilizer, a gain of four bushels of wheat was secured from the use of $1.20 worth, making a net gain of about $2.50 per acre. It is quite evident that a complete fertilizer cannot be used economically at the rate of 600 lbs. per acre where an increase of only eight bushels per acre is obtained. In order that a commercial fertilizer may be used profitably, the nitrogen must be obtained through the production of clover, as was the case on this farm. Since this soil was well supplied with nitrogen, the phosphoric acid and potash were both used to advantage, resulting in a financial return from their joint use. Commercial fertilizers cannot be indiscriminately used upon all soils. In these trials beneficial returns were secured from the use of phosphoric acid and potash, and it was found unnecessary to supply nitrogen in commercial forms, while in the previous experiments, on land where clover had not been grown, applications of nitrogen were found slightly beneficial, but not economical.

A chemical analysis was made of the wheats grown upon the several plots, and the following results were obtained.

Kind of Fertilizer,	Protein	Ash
Nitrogen	15.19	.....
Complete	14.8	1.78
Phosphate	13.75	1.79
No Fertilizer	14.44	1.96

It is to be noted that, as in previous experiments, the application of nitrogenous fertilizers slightly increased the content of nitrogen in the grain. The effect of this gain in nitrogen upon the milling and bread making qualities of the wheat will be discussed in a following bulletin.

Experiments at Lynd, Lyon County.

These experiments were made upon the farm of Mr. O. C. Gregg, Superintendent of Farmers' Institutes. Mr.

Gregg states that special credit is due to Mr. W. C. Palmer in making the tests, particularly in staking off the plots and supervising the cutting and threshing of the grain; in this work Mr. Palmer was assisted by Mr. Tucker, the farm foreman, and by Mr. Carl Peterson. In these experiments oats were grown instead of wheat, and in addition special tests were made with a phosphate fertilizer on wheat. A comparative test was also made with barnyard manure. Mr. Gregg reported that the plot receiving the barnyard manure yielded 76 bushels per acre. The other plots gave the following yields:

Plot No.	Kind of Fertilizer	Yield per Plot	Yield per Acre
		Grain Lbs.	
1	Complete,	650	88¼ bu.
2	Phosphate,	530	66¼ bu.
3	Potash,	540	67½ bu.
4	Nitrogen,	560	70 bu.
5	No Fertilizer,	592	74 bu.
6	Barnyard Manure	....	76 bu.

The plot receiving 150 lbs. of phosphate fertilizer yielded 20 bushels of wheat and 3652 lbs. of straw, while the adjoining acre of land, to which no fertilizer was applied, produced 20 and two-thirds bushels of wheat and 4190 lbs. of straw. In this test, made on an acre plot, the phosphate fertilizer failed to increase the wheat yield. When this experiment was undertaken, it was believed that an application of phosphate fertilizer would assist the grain to fill more perfectly and would produce a larger yield, but these results were not secured. In the experiments with oats, the farm manure produced better yields than nitrogen, phosphoric acid or potash alone, but not quite as good a yield as the complete fertilizer. The increase from the complete fertilizer was 14¼ bushels per acre, but at this rate of increase the fertilizer was used at a financial loss. As oats are a strong feeding crop, it

is possible that some of the fertilizers might have shown different results with other grains, but so far as the test of a single season goes the fertilizers did not cause an increase in the yield of oats sufficient to pay for the fertilizer used. On Mr. Gregg's farm clover has been grown for a number of years, and consequently there is no reason why expensive nitrogenous fertilizers should be used for supplying the crops with nitrogen. As far as the minerals are concerned, it does not appear that this soil has yet reached that stage where mineral fertilizers are necessary, except possibly in cases arising from unbalanced growth of crops.

Experiments at Montevideo, Chippewa, County.

These tests were made by Mr. O. M. Olson, a graduate of the Minnesota School of Agriculture. Mr. Olson's report as received is given:

"The ground was old and had not been manured for many years. It was dragged before the grain (wheat) was drilled. The grain was sown April 5th, and the fertilizer applied April 11th, when the ground was again dragged. Fertilizer sown by hand. The plots were 30 ft. wide and of sufficient length to approximate a quarter of an acre. Border grain was sown on all sides of the experimental plots. 160 lbs. of complete fertilizer was sown on Plot 1. 40 lbs. of nitrogenous fertilizer on Plot 2. Then came a check plot. 80 lbs. of phosphate on plot 3, 40 lbs. of potash on plot 4, then two more check plots. All of the plots were uniform in size. Prior to harvesting, the following field notes were taken. Three estimates on crop condition and three measurements for height on similar parts of the plots were made and averaged.

Plot 1 showed no signs of crinkling or lopping of heads. Heads were large; average height 44 inches; a condition percentage of 85.

Plot 2 showed no crinkling; not as early in maturing, average height 43 inches, condition 80 1-3.

Check Plot. Heads apparently smaller, a trifle more matured than No. 2. Not so much sign of stiffness of straw; average height 41 2-3 inches; condition 77 2-3.

Plot 3 showed a weaker straw than any of the others, though not bad in any degree; no appreciable difference in heads; height 43 1-3 inches; condition 81 2-3.

Plot 4 showed a good, stiff straw, but lacked in height and size of heads. Height 41 inches; condition 77.

The other check plots were in keeping with the first, except for trifling variations in height and condition.

The results told by the threshing machine were practically in keeping with the growing estimates. Plots were threshed separately and yields reckoned by the machine's automatic weigher. Composite samples of each plot were taken and comparative grade made of each.

Plot No.	Fertilizer	Height in inches, 3 measurements, average	Yield bu.	Grade per cent	Yield per Acre	Con. in Growing, Aver. of 3 Measurements
1	Complete	44	6 25	93	25	85
2	Nitrogen	43	5	87	20	80⅓
3	Phosph'te	43⅓	6	89	24	81⅔
4	Potash	41	5	94	20	77
Check Plots		41½	5	90	20	78

From Mr. Olson's report it will be observed that the phosphate fertilizer gave an increase of four bushels per acre over the plots receiving no fertilizer. No increase was secured from either the potash or the nitrogen alone. In the case of the complete fertilizer, 5 bushels per acre were obtained, a bushel more than from the phosphate fertilizer alone, showing that the more expensive complete fertilizer is used at a loss when only one element of fertility, as phosphorus, is needed by the soil. The four bushels increase from the phosphate fertilizer was secured from $2.40 worth of fertilizer.

Experiments at Hanska, Brown County.

These experiments were conducted by Mr. Carl Olstad, a graduate of the Minnesota School of Agriculture. Mr. Olstad reported that the complete and the nitrogenous fertilizers produced better appearing crops than either the potash or the phosphate fertilizer when used alone, and that on the plots receiving nitrogen the grain was six

inches higher than on the other plots; but the nitrogen retarded the ripening of the grain. There was a little heavier stand of grain on the plot receiving the complete fertilizer. The plot receiving the potash fertilizer produced a very bright straw and one of good quality. The weakest straw was produced on the plot receiving the nitrogen fertilizer. On all of the plots clover and timothy were seeded with the grain, and on the plot receiving the phosphate fertilizer the stand of clover was exceptionally good, equal to that on the plot receiving the complete fertilizer, while the clover on the plot receiving the nitrogen did not appear to be especially benefited, neither did that receiving the application of potash. It is to be noted that the phosphate fertilizer was especially beneficial in encouraging the growth of clover, and Mr. Olstad stated that he believed lack of available phosphoric acid in the soil was in part accountable for the failure of clover to establish itself on old and wornout farms. At the time of harvest, through a misunderstanding, the farm help failed to keep the plots separate, so that separate threshing of the plots, as was intended, could not be carried out. Mr. Olstad reported that he did not believe any large differences would be observed in the yields of the separate plots indicating any marked superiority of the different fertilizers.

Experiments at Renville, Renville County.

These experiments were conducted by Mr. N. J. Holmberg, a graduate of the School of Agriculture, who writes:

"The results of the experiments with the commercial fertilizers are as follows. The results are given in bundles, as it was impossible for me to thresh the plots separately.

Complete fertilizer	95	bundles
Potash fertilizer	92	"
Nitrogen fertilizer	90	"
Phosphate fertilizer	90	"
No fertilizer	85	"

I think the reason the complete fertilizer gave the best result is that it distributed much more evenly than the other fertilizers. The grain drill was used with good result on the complete fertilizer, but the other fertilizers would not feed in the drill without some agitation and consequently the distribution was not as even as of the complete fertilizer. The phosphate was exceedingly difficult to distribute except by hand. The nitrogen was applied somewhat unevenly and the grain lodged in spots, which was probably due to too heavy application in patches. The grain was all good in quality. The land used was high, good land, but had not received any fertilizer before. I think that it is hard to draw any definite opinion from this one trial, as the conditions were exceptionally favorable for a good crop. Land that was thought worn out gave a heavy crop of wheat here. This was high land, and we had moisture enough to give the best results. This acre, divided into five plots, will make a yield of at least 25 bushels."

Experiments at St. Cloud, Stearns County.

These trials were conducted by Mr. Arthur Cooper, and the fertilizers were applied to wheat and oats grown together as "Succotash," to be used for feeding purposes. The fertilizers were mixed and used thus on an acre and a half of land, forming a complete fertilizer. Mr. Cooper reports that from this acre and a half about 8 bushels more grain was secured than where common stable manure had been applied.

Experiments with Corn.

Similar experiments to those with wheat were carried on with corn. The same fertilizers were sent out in amounts sufficient for approximately 1/8th of an acre each. The reports received from those who made the fertilizer trials with corn are given in the following pages. All of the trials were made either upon the farms or under the supervision of graduates of the Minnesota School of Agriculture, and to them special credit is due for so painstakingly carrying out the details of the tests and reporting the results.

Experiments at the University Farm, St. Anthony Park.

These tests were made in co-operation with the Division of Agriculture.

University of Minnesota No. 13 corn was sown on all of the plots May 1st. The plots were so arranged that there were twelve rows of corn in each plot. The corn was husked on Nov. 11th, and the following weights per acre of stover and corn were obtained:

Plot No.	Kind of Fertilizer	Weight of Corn per Plot	Weight of Stover per Plot	Bushels of Corn per Acre	Weight of Stover per Acre Tons
1	Nitrogen,	460	348	53.2	1.4
2	Phosphate,	309	354	36.5	1.4
3	Potash,	554	506	64.1	2.1
4	Complete,	514	457	59.4	1.9
5	None,	500	442	57.8	1.8

From the results it will be observed that on the plot where no fertilizer was used 57.8 bushels per acre were secured, while the plot to which the complete fertilizer was applied produced 59.4 bushels. The largest yield was obtained from the plot to which the potash was applied, and the smallest from the plot receiving the phosphate fertilizer.

Since these experiments are to be repeated the present year, no conclusions are drawn. It is evident, however, that the nitrogen, phosphate and complete fertilizer did not increase the yield of the grains, and whether the 6.3 bushels per acre increase on the plot receiving the potash fertilizer was due to other causes cannot be determined from the conflicting data secured. The potash in the complete fertilizer failed to produce any appreciable gain, although when used alone and in larger amounts an increase of 6.3 bushels resulted. As far as the grade of the corn is concerned, there appeared to be little difference between that produced on the several plots, as all were graded the same in size and general character.

Experiments at New Ulm, Brown County.

These experiments were made upon the farm of Mr. Herman Pfaender. Mr. Pfaender's report of the yields from the plots to which the various fertilizers were applied is as follows:

"The corn was planted May 13th. Seed used U. of M. No. 13. Land, a very poor, sandy ridge. All land had previously been given a coat of barnyard manure, applied with spreader at rate of 15 loads per acre. The commercial fertilized plots all showed more vigor from the very first. In stalks, the potash ranked first, next nitrogen, next complete fertilizer, next phosphate. To make the comparison in yield, I husked only 50 hills of each kind, which yielded as follows:

Complete fertilizer	51 lbs.
Potash fertilizer	48 lbs.
Nitrogen fertilizer	54 lbs.
Phosphate fertilizer	28 lbs.
No commercial fertilizer used	26 lbs."

From the tests made by Mr. Pfaender, it is evident that nitrogen and potash were the controlling elements in causing the increase in yield of the corn and that, under the conditions of the experiment, the potash was used advantageously, as it increased the yield more than enough to pay for itself. As to the nitrogen, it could have been obtained from cheaper sources, as indirectly by the production of legumes, although its joint use with the potash increased the yield.

Experiments at Zumbro Falls, Wabasha County.

These experiments were carried on by Mr. David Boss, who furnished the following report:

Plot No.	Kind and Amount of Fertilizer	Lbs. Corn	Yield per Acre
1	Good coat of barnyard manure,	390	43.2
2	50 lbs. complete fertilizer,	335	37.2
3	20 lbs. Nitrogen,	309	34.3
4	40 lbs. Phosphate,	325	36.
5	20 lbs. Potash,	364	40.4
6	No fertilizer at all,	308	33.8

"The plots were ⅛ of an acre each. The soil of these plots had been under cultivation about 40 years. During that time it had raised 3 or 4 crops of clover hay and received two coats of manure. The plots were planted to Minn. 13 corn the 10th day of May, and cut the 10th day of September. The corn on Plots 1 and 5 seemed considerably firmer on the cob than that on the other plots."

It is to be observed that the application of the nitrogen fertilizer scarcely affected the yield, and the phosphate increased the yield only 2.2 bushels per acre. The potash alone gave better returns than when used in the complete fertilizer. The largest returns were secured from the plot receiving the dressing of farm manure. It is doubtful whether commercial fertilizers can compete with farm manure in the production of corn under the conditions described in this test.

Experiments at Elk River.

These experiments were conducted by Mr. Samuel R. Houlton, who sent the following report:

"I would say with regard to fertilizer experiment on corn, the fertilizer was applied on level piece of fairly good sandy loam soil which had received no manure for about three years. The following are yields received per plot:

	Bushels.
Nitrogen	9½
Phosphoric acid	9½
Potash	9½
Combination fertilizer	9¾
No fertilizer	9¼ to 9½
Barnyard manure, rather heavy	11

Variety of corn used, Minn. No. 13."

The nitrogen, phosporic acid and potash, whether applied alone or in combination, had little effect upon the yield, as practically the same amount was obtained from each plot, but the application of barnyard manure in liberal amounts caused an increase of 1½ bushels of ear corn per plot, or 12 bushels per acre. As in the preceding experiments, the effect of farm manure in increasing the

yield of corn was more pronounced than of the commercial fertilizers.

Experiments at Buffalo, Wright County.

These experiments were conducted by Mr. R. N. Mills, who reports that he secured the following yields from the application of the various fertilizers:

	Bushels.
"Nitrogen	13¼
Phosphate	13
Potash	14¼
Complete fertilizer	13
No fertilizer	13½

The fertilizer was applied to corn in six rows of the required length, the different plots being side by side. The corn was a yellow dent that had been raised in this part of the country for at least 20 years."

It is to be noted that the fertilizers had no appreciable effect in increasing the yield, with the exception of the potash, which caused an increase of about eight bushels of ear corn per acre.

Experiments at Worthington, Nobles County.

These experiments were conducted by Mr. Milton Ludolw, who reports that on the plots to which the complete and potash fertilizers were applied the stand was uneven because of partial destruction of the crop by gophers, and the yields from these plots were deficient on that account. From the quarter acre plot fertilized with the nitrogen 20 bushels of corn were secured, while the plot to which the phosphate fertilizer was applied yielded 22 bushels. The adjoining field, which received no fertilizer, yielded corn at practically the same rate as the plots on which the phosphate and nitrogen fertilizers were used.

Experiments with Potatoes at North Branch, Pine Co.

These experiments were conducted by Mr. Thos. H. Horton on land that had been in clover and timothy the

preceding year. The soil was in good condition as to fertility. The plots were uniform, with the exception of the one to which nitrogen was applied, where there was a slight rise at the end of the plot. Mr. Horton states that it is possible the poorer showing of this plot may have been due somewhat to this. The proportion of small and defective potatoes from each plot was about the same. The yields of sound potatoes from the several plots were as follows:

Plot No.	Kind of Fertilizer	Bushels per Plot
1	No Fertilizer,	22½
2	Nitrogen,	20
3	Complete,	25
4	Phosphate,	20¼
5	Potash,	19

The yield of all of the plots was somewhat affected by blight. Neither the potash, phosphate nor nitrogen, when applied alone, appeared to appreciably increase the yield, but when the complete fertilizer, containing all of the elements, was used there was a slight increase in the yield, not sufficient, however, to pay for the fertilizer. The fertilizers will probably make themselves felt later in the production of clover, and a part of their value be returned indirectly in this way. As far as direct benefit to the potato crop was concerned, the increase in yield was not sufficient to pay for the fertilizers used.

SUMMARY.

SUMMARY TABLE.—Experiments with Wheat and Oats. Fertilizer Trials.

BUSHELS PER ACRE.

	London Old Wheat Land	Benson Clover Land	Monte-video	Ex. Station	Lynd	Lynd (Oats)
No Fertilizer.....	7.3	15	20	27.25	20⅔	74.
Complete.....	10.8	24	25	24.	.....	88.25
Phosphate.....	7.2	20	24	26.8	.....	66.25
Nitrogen.....	10.2	16	20	29.25	20	70.
Potash.....	9.8	20	20	24.	.....	67.5
Farm Manure.....	.....	.....	.....	.....	.....	76.

SUMMARY TABLE.—Experiments with Corn. Fertilizer Trials.

	Ex. Station Bu. per acre	*New Ulm Pounds	Zumbra Falls Bu. per acre	Elk River Bu. per acre	Worth-ington Bu. per acre
Nitrogen.....	53.2	54	34.3	38	80
Phosphate.....	36 5	28	36.	38	88
Potash.....	64.1	48	40.4	38	.....
Complete.....	59.4	51	37.2	38	.....
No Fertilizer.....	57.8	26	33.8	37	84
Farm Manure.....	.....	.....	43 2	44	.....

*Per 50 hills.

It is to be observed in the case of the old soil that was reduced in crop producing power because of exclusive grain culture until it produced only 7 bushels of wheat per acre, that an application of nitrogen, phosphoric acid or potash, alone or in combination, did not result in raising the yield more than 3.6 bushels per acre, not enough to pay for the fertilizers. The commercial fertilizers failed to give as large yields per acre as was secured from adjoining land kept in a good state of

fertility by the rotation of crops, the use of farm manures and the cultivation of clover.

On a grain-cropped soil, where clover had been grow, applications of phosphoric acid and potash resulted in increasing the yield 8 bushels per acre, sufficient to pay for the fertilizers used, while the addition of nitrogen did not prove economical.

In one of the experiments phosphoric acid alone gave beneficial results, causing an increase in the crop yield of four bushels per acre, and in other tests its use produced a better stand of clover.

At the Experiment Station, on land in a fair state of fertility which without fertilizers produced 27 bushels of wheat per acre, no appreciable increase was secured from the use of commercial fertilizers.

The addition of nitrogen-containing fertilizers to old and exhausted wheat soils increased the protein in the grain from one to three per cent. The influence of this increase of protein upon the value of the grain for milling and bread making purposes will be discussed in later bulletins.

In the experiments with corn, it was found that in three of the tests potash gave beneficial results, insufficient, however, to pay for the fertilizer used. In two of the tests phosphoric acid appeared to exercise a beneficial influence upon growth. In the trials where commercial fertilizers were compared in crop producing power with farm manure, better results were secured from the use of farm manure than from the commercial fertilizers.

It is not possible to draw definite conclusions from trials conducted during one season only, but the results taken as a whole indicate that commercial fertilizers should not be used indiscriminately on old soils with a view of securing large yields, and it is not feasible by the use of commercial fertilizers alone to economically restore the fertility to soils that have been impoverished by exclusive

cropping to small grains. Commercial fertilizers are of great value when judiciously used in a rotation of crops and for encouraging the growth of legumes, as clover, so as to add nitrogen to the soil from atmospheric sources. It is believed that when they are used in this way they will prove beneficial and remunerative. Before using them in large amounts it is recommended that farmers first make preliminary trials on a small scale to determine the actual needs of the soil so that unnecessary elements of plant food be not purchased. Commercial fertilizers cannot take the place of farm manures or crop residues, particularly those from clover and timothy, for permanently improving the soil, but they can be used as an aid in the production of some crops, and for assisting in the production of others, as clover, which are in turn beneficial in adding nitrogen and humus to the soil.

The extent to which commercial fertilizers can be used in a rotation of crops and in a general system of farming is to form the basis of future investigations and reports.

THE LOSS OF NITROGEN FROM SOILS.

HARRY SNYDER.

In former bulletins the influence of different methods of farming upon the nitrogen content of soils has been discussed and in the case of those that have been exclusively cultivated to grains it was found that large losses of nitrogen occur. In some of the experiments at the University Farm it was learned that the main loss of nitrogen is due to oxidation of the humus, of which nitrogen is one of the constituent elements, rather than to the removal of large amounts by the grain crops. A crop of wheat yielding 30 bushels per acre removes less than 40 pounds of nitrogen per year, but tests have shown that in twelve years of exclusive grain cultivation the loss of nitrogen in the case of rich soils has approximated 1600 lbs. per acre. Numerous analyses of soils that have been under cultivation for different periods have shown similar losses of nitrogen. In some cases the losses have been very large, while in others, where mixed farming was followed, they have been comparatively small.

In order to determine the extent to which losses of nitrogen occur from an average farm, experiments upon a number of typical farms in the state were undertaken in 1895. Samples of soils from representative fields were obtained and analyzed. Ten years later samples from the same fields were again taken and analyzed, and the extent to which losses of nitrogen had occurred was determined. The soils were originally sampled by young men who were then students of the Minnestota School of Agriculture; about ten years later other samples were taken by the same persons and from the same places and fields. It is believed that this gives a reasonable basis for making com-

parison as to the extent of the losses of nitrogen from these fields.

At Kennedy, Kittson County, a soil of unusually high fertility contained in 1895 .601 per cent of nitrogen. It is seldom that a soil is found with such a large amount, but, as pointed out in previous bulletins, the soils of the Red River Valley are excessively rich in nitrogen except in cases where they have been under long periods of cultivation. After ten years of exclusive grain farming, in which wheat was the main crop produced, the land being one year in fallow, the soil contained .523 per cent of nitrogen, a loss during that time of 2,000 pounds per acre. The wheat crops during this ten year period removed less than 350 pounds. Hence the heavier losses have occurred through too rapid decay of the humus, of which nitrogen forms a part, and subsequent loss of the soluble nitrogen in the drain waters, and by the formation of volatile compounds of nitrogen. The soil still contains a large amount of nitrogen; in fact, ten times more than is found in some soils that are producing fair yields of wheat. The loss of nitrogen from this soil has not been sufficient as yet to appreciably affect its crop producing power.

At Childs, Wilkin County, in the central western part of the state, a sample of soil in 1895 contained .422 per cent of nitrogen, and ten years later .389 per cent. On this farm live stock has been kept and, in addition to wheat, corn and other crops have been grown. Once during the ten year period manure at the rate of 8 tons per acre was applied to the land. No clover or grass crops have been grown. It is to be noted that from this farm, where the soil is rich in nitrogen but contains less than the soil in the preceding experiment, the losses have been proportionally less, due in part to the different systems of soil treatment practiced. A loss of .033 per cent of nitrogen in ten years is equivalent to a loss of nearly 1,000 pounds per acre. It is estimated that one-third of this

has been removed by the grain crops and two-thirds have been lost in other ways. The large amount of nitrogen in this and the preceding soil occasionally makes itself manifest in unbalanced crop growth, the nitrogen becoming available in larger proportional amounts than the phosphoric acid and potash of the soil, and as a result the crop makes a rank growth of straw and a restricted yield of grain. On some of these rich soils it is often difficult to adjust a satisfactory rotation of crops, as the farther addition of organic matter sometimes unfavorably affects the balance of the plant food. These soils are exceedingly rich in nitrogen and can, without seriously impairing the crop producing power, sustain farther losses, but heavy losses should be prevented as they are unnecessary and will, if continued, make themselves felt in an impoverished condition of the soil. If more live stock were kept and mixed farming were more extensively followed, the losses of nitrogen would be much reduced.

At Hutchinson, McLeod County, in the central part of the state, soil in 1896 contained .286 per cent of nitrogen, and ten years later the same field showed .247 per cent. Wheat, oats, corn and barley have been the crops produced during this time. The land has received a dressing of farm manure, but no clover or grass crops have been grown. It is to be observed that, during the ten years, a loss from the soil of .039 per cent of nitrogen has taken place, amounting to nearly 1200 pounds, a much larger loss than the amount required as food for the crops produced. It has been observed in former work that the heaviest losses of nitrogen occur in the case of soils which contain the largest amounts of nitrogen, and that the fermentation and decay of the humus is much slower in soils where the content of humus and nitrogen is comparatively small. It is the rich soil that suffers heaviest losses. It is to be noted that, in the case of mixed grain farming as in this last example, even where manure is periodically re-

turned to the land, if no grass crops are grown loss of nitrogen is continually taking place. The soil, however, is still rich in nitrogen and produces good crops of wheat, but if a rotation were followed in which clover formed an essential part, this loss of nitrogen would be checked.

A soil in the Chippewa River Valley, in the southwestern part of the state, in 1895 contained .363 per cent of nitrogen. Since that time it has produced wheat, oats and corn and received one light dressing of manure. At the end of ten years of cultivation the soil contained .24 per cent of nitrogen, a loss of .12 per cent. Notwithstanding this loss, the soil is still rich in nitrogen and the crop producing power has not been affected. Unless clover is grown the loss will, however, in a few years make itself felt materially in the reduced grain yields.

A soil at Lakeville, Dakota County, contained in 1895 .31 per cent of nitrogen. During the subsequent ten years wheat, oats, corn and clover were grown. The land was manured once during this period, at the rate of 20 tons of manure per acre. Mixed farming has been followed and only a small amount of grain has been sold from the farm. This system of farming has had a marked effect upon the nitrogen content of the soil, as, after ten years of cultivation, .309 per cent of nitrogen was found, practically the same amount as at the beginning. Live stock was the principal product sold from this farm, the income being derived from the sale of sheep, hogs and cattle. Practically all of the crops raised on the farm were fed to the live stock. The farm crops were supplemented by the purchase of a small amount of bran and shorts. Under this system of farming the yield of wheat has been increased and the last year that wheat was grown an average of 28 bushels per acre was secured. The rotation followed upon this land was wheat, seeded to clover; one year of meadow; followed by corn to which manure was applied; and then two grain crops following the corn. Because of the production of clover, practically no loss of

nitrogen has occurred. Losses of phosphoric acid and potash have been very small. The effect of the farm manure upon the soil has more than offset the small amount of mineral matter lost in the live stock and farm products which have been sold. In fact it is largely the action of the farm manure upon the mineral matter of the soil, making it more active and available as plant food, that has resulted in incresing the crop producing power of this soil.

Since clover has been a prominent factor in building up the fertility of soils, it occupies a unique and important position among farm crops, and the conditions affecting its growth have naturally received a good deal of consideration from both scientists and practical farmers. Atmospheric nitrogen acquired by the action of the bacteria which are on the clover roots is the source of the increase of nitrogen in soils where clover has been grown. In order to insure the action of the clover root bacteria, inoculation of seed and soil with the characteristic organisms has been proposed, and in many instances it has materially assisted in the production of better crops of clover and the addition of larger amounts of nitrogen to the soil. Various forms of inoculating materials or cultures have been proposed, as soil taken directly from a field where clover has grown and produced root nodules, leachings from such soil, prepared liquid cultures, and prepared dry cotton cultures. The extensive publicity given to the production of the ltter has resulted in many letters in regard to their value being received at the experiment Station. About twelve years ago the late Dr. Lugger then Botanist of the Minnesota Experiment Station, imported from Germany a number of liquid cultures for the inoculation of soils, including the clover culture preparation. These were tried in pot experiments with soils from about twenty different places in the state, and in no case was any special benefit derived from their use. From these and other tests Dr. Lugger concluded that the nitrogen-fixing organisms associated with the clover plant were

quite generally present in the soils of the state and that the use of these preparations was unnecessary.

Also later tests made by the Minnesota Experiment Station show that the characteristic nitrogen-fixing organism of clover is widely distributed in this state and that on soils where clover is produced for the first time the roots have an abundance of well developed nodules. In fact, clover grows luxuriantly in nearly every part of the state, and in the Northeastern part it is practically indigenous. Because of these facts, the general use of cultures for inoculating soils has not been recommended by this Station.

A recent bulletin of the New York Experiment Station has shown that the commercial cotton cultures are of no value for the production of clover. When the cultures were examined, they were found not to contain or to be capable of producing any of the organism that carries on the work of nitrogen fixation. Even the few cultures prepared and sent out by the U. S. Department of Agriculture were found to give negative results. At one time the U. S. Department of Agriculture distributed these cotton cultures extensively, but later experience showed them to be unsatisfactory.

In this state clover failures have been found to be due in most cases to poor seed, lack of proper preparation of the seed bed, or to lack of available phosphoric acid and potash in the soil. Poor seed has probably more often been the cause of failure of the crop than all other causes combined. As shown in a former bulletin, No. 34, of this Station, the soils of this state are chemically and physically well adapted to the production of clover. The prevalence of the nodules on the roots of clover and the negative results of the inoculation tests show that general inoculation of the soil is unnecessary in Minnesota for the production of clover to restore nitrogen to old grain soils.

SUMMARY.

The loss of nitrogen from four grain farms in ten years amounted to from three to five times more than was removed by the crops. This loss was due to the rapid decay of the humus and the liberation of the nitrogen, which forms an essential part of the humus. The losses of nitrogen from these grain farms were practically the same as from the experimental plots at the University Farm. The results of the tests on the small plots are in accord with the field tests in different parts of the state.

Where clover was grown, crops rotated, live stock kept, and farm manure used, an equilibrium as to the nitrogen content of the soil was maintained, the mineral plant food was kept in the most available condition and maximum yields were secured.

The summary of results of Fertilizer Tests with wheat and corn is given on pages 185, 186 and 187.