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Rotation of Crops

UNIVERSITY OF MINNESOTA.

Agricultural Experiment Station.

BULLETIN No. 109.

DIVISIONS OF AGRICULTURE AND AGRICULTURAL CHEMISTRY AND SOILS

JUNE, 1908.

THE ROTATION OF CROPS.

1. REPORT OF 10 YEARS ON 44 ROTATION PLOTS.
2. INFLUENCE OF ROTATION OF CROPS AND CONTINUOUS CULTIVATION UPON THE COMPOSITION AND FERTILITY OF SOILS.

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UNIVERSITY OF MINNESOTA.

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SUMMARY.

1. There is choice even among good rotation schemes. In these experiments all those cropping systems gave large net profits in which corn, small grains, and timothy and clover sod laid for one to four years, were arranged in a four to seven year rotation, with light manuring once during the course.

2. The standard five year rotation followed on the check plot is: First year, corn, following the application of eight tons of manure per acre; 2nd year, wheat; 3rd and 4th years, meadow; 5th year, oats. This rotation has given an average gross income per year, based on average farm prices, of $14.08. The cost of production, including $3.50 land rental, is $9.05, leaving a net annual income of $5.03 per acre.

Several other rotation schemes were even more profitable than the one used for a standard; while crops grown continuously and crops not properly arranged in the rotation were less profitable or even resulted in a loss.

4. The best rotations in these experiments have yielded a product worth from four to six dollars per acre more than is obtained on the average farm throughout the state.

5. Many Minnesota farmers would profit were they to practice systems of cropping which include the alternation of grain crops, grass crops as clover and timothy sown together, and cultivated crops arranged in any rotation scheme best suited to their conditions.

6. The experimental evidence (see Part II.) shows that the use o fmanure and clover add to the nitrogen and that manure, also clover and timothy, add fresh vegetable matter to the soil.

7. Any systems of cropping that have provided for the maintenance of a supply of vegetable matter in the soil, either by manuring or by growing pasture or meadow crops, have given profitable returns.

8. The plots which have grown cultivated crops, such as corn, potatoes and mangels, continuously without manure, have given poorer returns than have the plots which have grown grain continuously without manure. This is believed to be due to the fact that the intertillage given these crops has caused a more rapid depletion of vegetable matter than has taken place in the continuous grain fields.

9. The four-year rotation: First year, millet; 2nd year, barley; 3rd year, corn; 4th year, oats, on Series II, Plot 5, gave no better returns than did the plot on which wheat was grown continuously. All of the crops in this rotation are considered exhaustive crops, as they all decrease rather than increase the supply of vegetable matter in the soil.

10. The practice of sowing grass seed with the grain on corn land that is disced in the spring in place of fall plowing, has resulted in securing a grass stand in nearly every instance. It has proved to be the surest method of obtaining a grass stand of any tried at University Farm.

THE ROTATION OF CROPS.

W. M. Hays, Andrew Boss, A. D. Wilson.

The rotation of crops has for its object an increase in the yield per acre without a corresponding increase in the cost of production.

The experiments with crop rotations herein reported have been conducted to allow the plants grown in the ordinary field way to tell their story concerning which scheme of cropping pays best in Minnesota, and incidentally to serve in throwing light on our soil problems.

The results of the rotation experiments reported in this bulletin bear evidence that a good system of rotation will very materially increase the net earnings of many Minnesota farms.

It is believed that these preliminary ten years of experiments have given results upon which can be based a saner cropping system throughout the State.

Chemical, physical and biological studies of the soil, and experiments determining how crops yield under varying conditions, as in continuously growing a given crop, or in growing crops in rotation, are gradually unraveling the mysteries of soil fertility. The soil is so complex in its relation to crops that it has been and still is one of nature's greatest puzzles. Its solid mineral particles, making up the body of most soils, its small per cent of decaying organic substance mainly of plant origin, its water distributed in exceedingly thin films over the surfaces of the particles, its abounding species of bacteria operating in the water on the decaying plant substances and affecting the solution of the minerals, minute quantities of mineral and organic compounds in the soil water, fungus plants, and the ever acting and hungry roots of crops constantly taking in from the soil mineral and nitrogenous food and giving out solvents, make of this an almost bewildering maze of physical, chemical and biological changes. It is not strange that scientists are slow in arriving at an understanding of or that no one is now prepared to comprehensively state the laws of fertility. The study of the biological activities in the soil is throwing new light upon the chemistry of fertility; and the study of soil chemistry will continue to show many facts concerning the preparation and use of plant food in the soil.

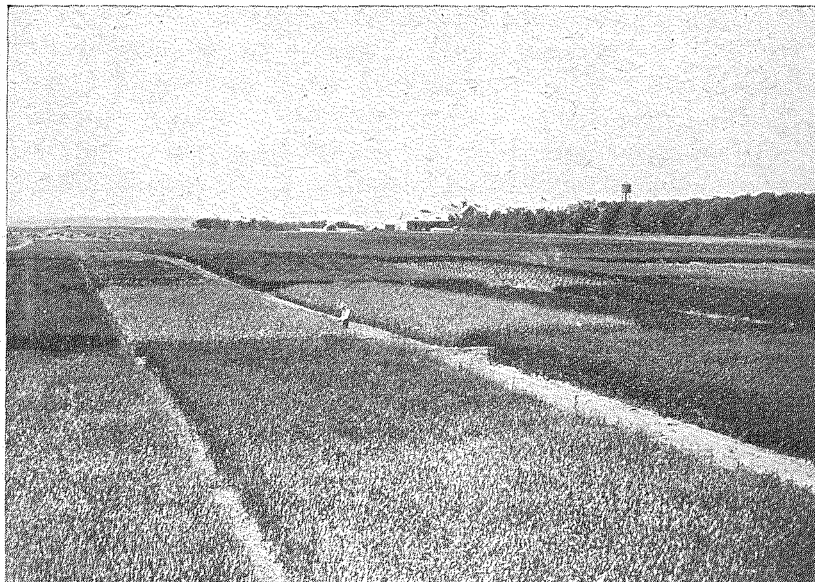


Fig. 1.—General view of part of the 44 Rotation Plots.

The best rotations in these experiments have yielded a product worth from four to six dollars per acre more than is obtained on the average throughout the state. This indicates that Minnesota farmers would profit were they to practice some of the systems of rotations which these experiments have proved successful· These experiments most forcibly emphasize the fact that the application of fresh vegetable matter in the form of barn manure and clover crop residues are a necessity to keep up the productivity of the soil for cultivated and grain crops.

There is no "one" best rotation scheme. Almost all schemes in these experiments in which grass crops were alternated with the grain and cultivated crops, and especially if barnyard manure was also applied once in several years, resulted in large yields of grain and cultivated crops, and gave large net profits per acre.

Does Continuous Cropping Exhaust Available Plant Food.

A view very generally accepted is that by the rotation of crops the soil receives a rest, that is, the plant food needed by the different crops varies, one crop removing one set of substances one year and a different crop a different set of substances the next year thus giving the soil a chance to build up for a certain crop between the years it is called upon to produce such crop. According to this contention, if a certain soil is called upon to produce the same crop or class of crops for a number of years it becomes exhausted of the particular kind of plant food needed by those crops and small yields are the result, In spite of the fact that this view is generally accepted, it is in the main doubtless incorrect. The elements of plant food which are likely to be lacking in the soil, are nitrogen, phosphoric acid and potash. According to this idea, when a soil ceases to be productive it is because it has become exhausted of the available portion of one or more of these substances. The fact that when our soils are continuously cropped to grain for several years the yield gradually decreases, and when a rotation is practiced, the yields are maintained or increased, might easily lead one to accept the above explanation. However, the following table based on actual crop yields shows that more of these elements are removed by the rotation than by the continuous cropping to wheat.

TABLE XLI.—Rotation Removes More Mineral Plant Food than Does Continuous Cropping to Wheat.

FIVE YEAR ROTATION. SERIES III. PLOT 1.			FERTILITY REMOVED		
Year	Crop	Yield	Nitrogen	Phosphoric Acid	Potash
1900	Wheat	23.3 bu.	40.8 lbs.	23.3 lbs.	40.8 lbs.
1901	Meadow	3.2 tons		76.8 lbs.	177.6 lbs.
1902	Meadow	2 1 tons		50.4 lbs.	116.3 lbs.
1903	Oats	59.0 bu.	59.0 lbs.	21.2 lbs.	53.1 lbs.
1904	Corn	58.3 bu.	96.8 lbs.	25.8 lbs.	77.4 lbs.
Total Fertility removed in 5 years			196.6 lbs.	197.5 lbs.	465.2 lbs.
Fertility added by 8 T. manure			81.6 lbs.	56.0 lbs.	81.6 lbs.
Total lost by rotation			115.0 lbs.	141.5 lbs.	383.6 lbs.
WHEAT CONTINUOUSLY SERIES III, PLOT 2					
(Total Yields 1900 to 1904 inc. 84.6 bu.) Total Fertility Removed in Five Years			148.0 lbs.	84.6 lbs.	148.0 lbs.
Excess Removed by Rotation			*-33	56.9 lbs.	235.6 lbs.

NOTE.—The figures for determining the amount of fertility removed by the various crops were taken from Prof. Snyder's "Soils and Fertilizers." The figures for determining the amount of plant food supplied by the manure were taken from Cornell Bulletin No. 27.

No nitrogen is charged against the meadow crops as the crop was about one half timothy and one half clover, and it is assumed that the clover added as much nitrogen as both crops removed.

That the five year rotation will give larger yields and continue to keep the soil in good condition for raising crops for a much longer time than will continuous wheat growing, is not doubted. Yet the fact remains as shown by the above table that eleven pounds more phosphoric acid and forty-seven pounds more potash are removed annually by the rotation than by the continuous cropping to wheat. Nearly seven pounds more nittrogen is removed by the continuous wheat than by the rotation; that is, assuming that all of the nitrogen added by the eight tons of stable manure applied to the five-year rotation could be utilized

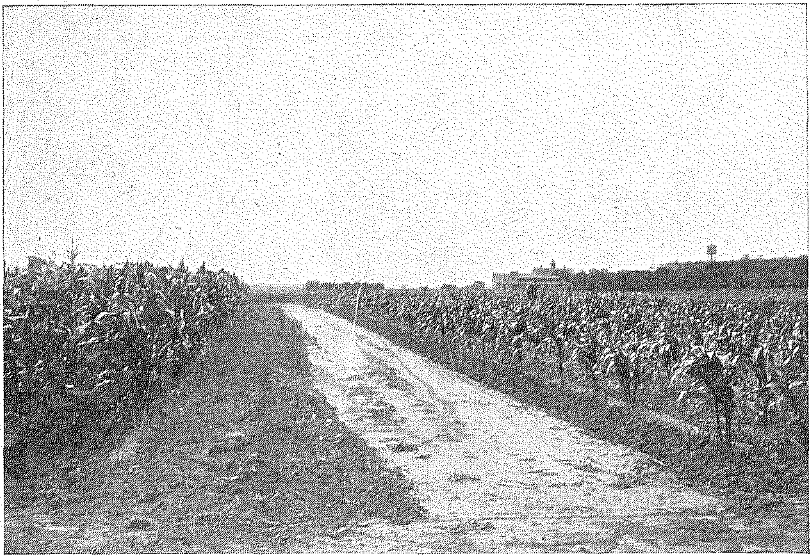


Fig. 2.—On the left is corn growing on one of the check plots, cropped to a five year rotation: (First year, 8 tons of manure, corn; 2nd year, wheat; 3rd and 4th years, meadow; 5th year, oats.) On the right is corn growing on a plot cropped to corn continuously, no manure. See discussion Series II, Plot 7, page 315.

by succeeding crops. It is more probable that one-third to one-halfof this nitrogen would be lost by leaching and by passing off as gas. This would leave the two systems practically even so far as the nitrogen removed by the crops is concerned. The advantages of following a rotation of crops over continuous cropping must be for some other reason than that the growing of the same kind of crop continuously removes too much of some particular element of fertility.

Rotation Improves Condition of Soil.

It is well known that vegetable matter or humus improves most arable soils. It at least improves soils that are somewhat run down by grain growing. Wherever partially decayed manure or roots are found in the soil, moisture is usually present, and such material also permits a free circulation of air. The real value of this condition of the soil is explained by the following facts. In order

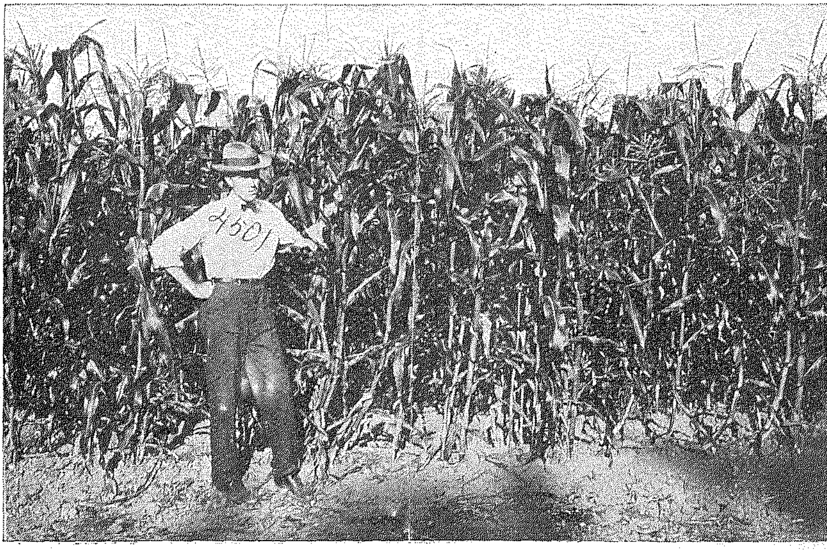


Fig. 3.—Growing fodder corn on newly broken alfalfa sod. Compare with Fig. 5.—Photo by H. D. Ayer.

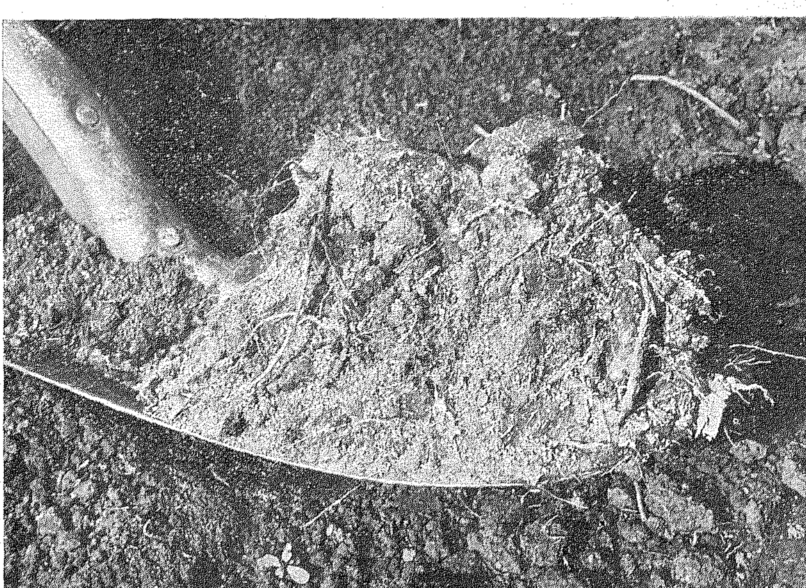


Fig. 4.—A shovelful of soil from the above plot, showing the vegetable matter present and the mellow condition of the soil. Compare with Fig. 6. Photo by H. D. Ayer.

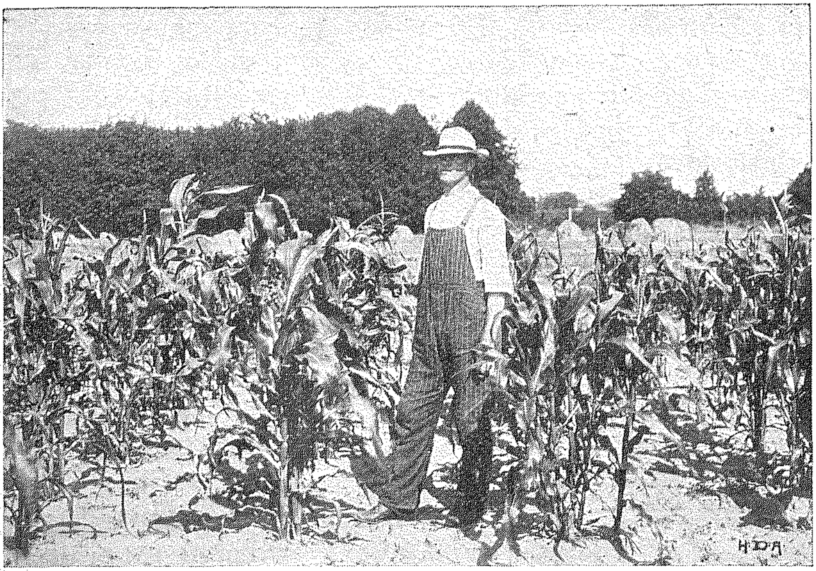


Fig. 5.—Growing corn on plot that raises corn continuously. Compare with Fig. 3.—Photo by H. D. Ayer.

Fig. 6.—A shovelful of soil from the above plot showing lack of vegetable matter and tendency to bake.—Photo by H. D. Ayer.

to grow, plants must have food in a soluble form in contact with their roots. Plant food is made soluble by the decomposition of organic matter and disintegration of mineral matter. Disintegration of mineral matter is aided very materially by the acids formed by decomposition of vegetable matter. Decomposition of organic matter in the soil takes place as the result of the action of bacteria and the bacteria which render plant food available can act only in the presence of air and moisture. (Further discussion of the action of vegetable matter upon the soil is given in the second part of this bulletin.) Hence the necessity of effectually maintaining that condition or texture of the soil which helps regulate the supply of air and moisture. It is not assumed that a soil is inexhaustible so long as a good physical condition is maintained, but it is assumed and amply proved by results reported in this bulletin that a soil in good physical condition remains productive much longer than does a soil in poor physical condition and that maintaining a good physical condition is the most practical way known of liberating and making use of the vast stores of mineral plant food locked in the soil.

The essentials of keeping the average soil in good physical condition are, to avoid an excess of water by drainage, if necessary, and to maintain a reasonable supply of vegetable matter. Heavy soils need vegetable matter to open them up and allow the air to circulate, and light soils need vegetable matter to hold the moisture and to check leaching, and all soils need vegetable matter as a source of easily available plant food. Vegetable matter is rapidly used up in a soil on which grain or cultivated crops are grown, and is most easily added to the soil by applying barnyard manure and growing grass crops.

Professor Snyder in Minnesota Bulletin No. 24, reporting results obtained in Freeborn County from the application of special and complete fertilizers, makes the following statement: "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 on which a rotation of crops had been practiced." From this the conclusion may be drawn, that where a naturally fertile soil is kept in good condition the necessary plant food is made available by decomposition and disintegration, and it also illustrates the fact that rotation puts the soil in the desired condition for promoting these chemical and biological changes. It is, therefore, quite evident, that one of the chief benefits of a rotation is, as has been stated, in its favorable influence upon the condition of the soil, so as to prepare the way for other changes.

It would seem then that the practical thing for the average Minnesota farmer to do is to aim to keep his soil in good condition by drainage, by good tillage and by so rotating his crops or manuring his fields, or both, as to maintain a reasonable supply of vegetable matter.

Much stress is here placed on the value of vegetable matter in the soil because the experiments herein reported indicate so conclusively that managing the soils of Minnesota so as to maintain a reasonable supply of vegetable matter will materially increase the yields, which are now far too low. Vegetable matter may be added to our soils much more cheaply than commercial fertilizers and it is earnestly hoped that our western farmers may not make the mistake made by many New England farmers who depended on commercial fertilizers until their soils no longer responded sufficiently to pay for the fertilizers applied and then were forced to abandon their farms.

Commercial Fertilizers.

There may be a few cases now and possibly more in the future where the soil is, or will become actually deficient in some of the elements of plant food, though such a condition is not likely to occur for many years in Minnesota. It is believed by the writers that the proper attitude of the farmer in regard to commercial fertilizers is to keep his soil supplied with vegetable matter by growing grass crops and manuring, and to grow clover often enough to keep up the supply of nitrogen. He should try on small plots the application of phosphate and potash fertilizers both separately and combined. If under such conditions the application of these fertilizers increases his yields enough to pay for the fertilizers applied, he is justified in investing in commercial fertilizers.

Lime or potash fertilizers often aid greatly in the growth of clovers. In such cases their use is warranted. It sometimes requires considerable effort to get a crop of clover on a run-down soil or on soil that has not before produced clover. The great value of clover as a soil renovater and builder warrants considerable expense in getting it started. Such cases can be determined by making trials on small plots.

Three Classes of Crops.

To simplify the planning of rotations, field crops are divided into three general classes according to their effect on the physical condition and available plant food of the soil. These three classes of crops are grain crops, grass crops and cultivated crops.

Under grain crops are placed such crops as wheat, barley, oats, millet, etc. These crops grow but one season, are sown usually in the spring, and are harvested without intermediate cultivation. They do not develop heavy root systems, consequently leave but little crop residue to keep up the supply of humus in the soil. During the years when grains are grown, weeds increase and the productivity of the soil decreases.

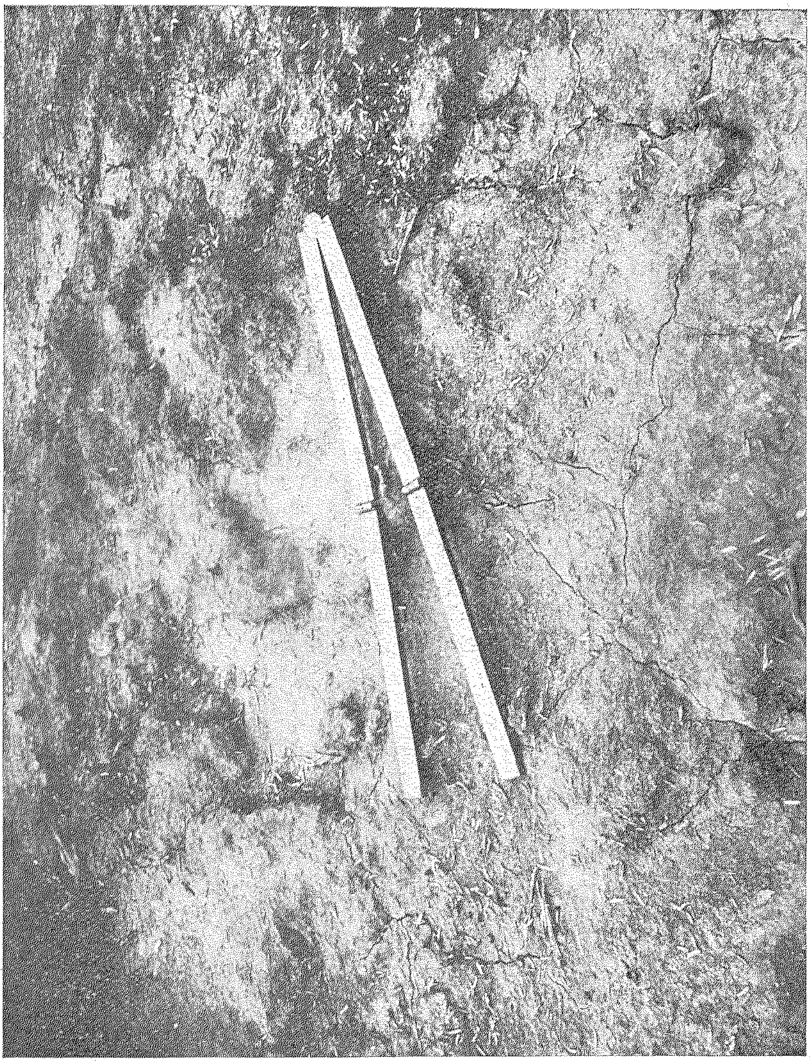


Fig. 7.—Soil as it appears after a heavy rain on a plot that grows corn continuously. The scarcity of vegetable matter allows the soil to pack so closely together as to exclude air. A soil in this condition is hard to cultivate, is likely to bake and crack, and it loses its moisture rapidly and produces small crops.—Photo by H. D. Ayer.

Fig. 8.—Soil in a corn field on a plot that grows corn once in five years, as it appears after a heavy rain. The 8 tons of stable manure added and the two crops of grass grown every five years maintain the supply of vegetable matter. As a consequence the soil remains much more mellow and more productive.—Photo by H. D. Ayer.

Grass crops include such crops as clover, (though not a true grass), timothy, bromus, etc. These crops grow two or more years from one seeding, consequently develop quite extensive root systems. When plowed up, the roots add materially to the supply of vegetable matter in the soil and in decaying leave open spaces between the soil particles which allow the entrance of air. These crops may be termed soil building crops.

The cultivated crops are those planted so as to allow intertillage during their growth. In this class are found corn, potatoes, and root crops such as mangels and sugar beets. The cultivation of these crops destroys weeds, loosens the surface of the soil, conserves moisture by the formation of a surface mulch and allows the entrance of air, thus making conditions favorable for the decomposition of vegetable matter.

It may be seen that a far better condition of soil is maintained by a good rotation of crops than by continuous cropping to corn or grain. The grass crops maintain the supply of humus and the cultivated crops retain moisture, destroy weeds and help to aerate the soil.

Instead of being a complex matter difficult to understand and impractical to follow, a systematic rotation of crops is one of the simplest and most easily carried out of any of the suggested improvements in methods of farming.

Crop Rotation Simple and Practical.

Crop rotation may be defined as a systematic succession of the three general classes of farm crops, namely, grain crops, grass crops and cultivated crops, in such a way as to provide large yields of grain, pasturage and forage needed on the farm at the least expense of labor and fertility.

Rotation systems must be adapted to each farm or class of farms and to the particular condition of each farm. With a knowledge of what it is desired to accomplish by rotation, namely an improvement in the condition of the soil and a corresponding increase in the net income per acre, it is easily possible, knowing the character of the farm, the climate, the line of farming desired and the tastes of the farmer, to plan a systematic rotation for that farm which will give the desired results. The essentials of a good rotation are that the net yields in money value per acre be maintained or increased, that vegetable matter be kept in the soil, and that the land be kept in good physical condition and reasonably free from weeds. Grass crops must be grown or barnyard manure applied, or both, to keep up the supply of vegetable matter. A cultivated crop occasionally and good tillage are necessary to kill out weeds and help put the soil in good tilth. These things are naturally brought about by alternating the three classes of crops—that is, one or more grass crops should appear on each field every four to eight years. Corn or other cultivated crops and manure should appear one or more years in the same period, and the remainder of the time grain may be grown.

This treatment cannot fail to keep the soil in much better condition than can be done by growing any one crop continuously, and it may be brought about by a very little planning, and without very seriously changing the acreage devoted to each crop. Most farms in the middle west have from one-eighth to one-half their tillable area in corn, and from one-eighth to one-half in grass each year. All the change that is necessary is to arrange these crops according to some regular system of rotation instead of growing each on the same field year after year.

Rotation Does Not Cause Smaller Fields.

A few people hesitate to begin the rotation of crops because they have the idea that it necessitates dividing the farm into small fields. It is true that a certain number of fields are necessary to carry out a rotation. It is also true that on the average farm a good rotation will provide fewer fields and better shaped fields than are used at present under the less definite systems of cropping. (Compare Figs. 9 and 10.

The above statement is made after studying a great many farms with a view to reorganizing them for rotations. If the reader will draw a rough sketch of his farm as it is cropped at the present time, showing the waste places and the areas devoted to each crop, the argument that rotation makes smaller fields than unsystematic farming will have less weight with him than at presentt.

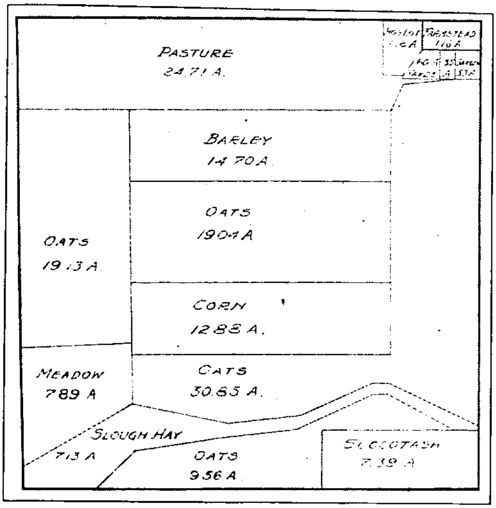


Fig. 9.—160 acre farm as cropped in 1904.

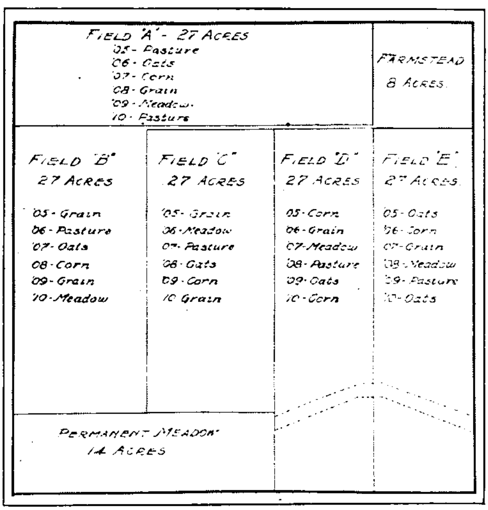


Fig. 10.—Same farm as above but remodeled for five year rotation, showing fields fewer in number, more regular and more easily reached from the farmstead.

When a plan of rotation is adopted the view of the farmer is changed. Instead of thinking only of the one crop he is seeding, he is looking ahead and planning to have that field prepared for crops one, two, or even ten years ahead. By knowing what will be sown on a field for several years in advance, labor may be saved, the yield increased, and arrangements made for making the best use of the crops grown.

Irregular Fields.

Some farms are so broken by waste land as to make the fields very irregular in shape and size. In such cases it is not easy to lay out straight, even-sized fields. Usually, by a little planning and careful management, the shape of such fields can be improved, and areas of nearly equal size can be laid off for the fields as well as on more regular farms. If necessary two smaller fields may be used as one field in the rotation.

Drainage.

One of the main causes of irregular fields is lack of drainage. Drainage is often quite expensive, and unless carefully done may be unprofitable. Yet there are few farms on which some drainage cannot be profitably done. The most annoying pieces on the farm are the low areas in the fields that can usually be plowed and seeded, but as a rule grow nothing but smart-weed or other useless plants. Such areas may be profitably drained at a comparatively high cost per acre. The cost of draining such areas may exceed the total value of the land drained and still make a profitable investment for if drained good crops could be raised without any extra cost, as it is never more work and often less work to farm a straight field than to farm around these small areas.

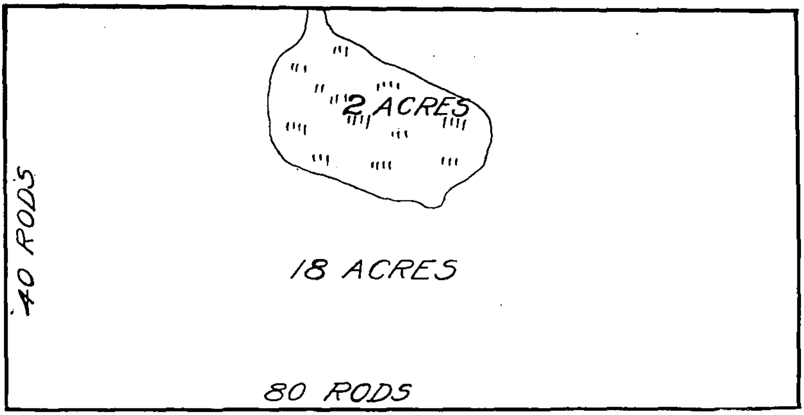


Fig. 11.—This 20-acre field could be worked as cheaply when drained as can the 18 acres now. The crop on the two acres would be clear again. Even $100 per acre for permanent drainage would be a profitable investment.

Experience in Reorganizing Farms.

In helping to reorganize for systematic rotations, the farms of some hundreds of students at the Minnesota School of Agriculture, it has been found that in most cases it is not necessary to materially change the acreage of the different classes of crops, but simply to re-arrange the sequence of the crops usually grown. Instead of growing grain and corn (humus destroying crops) continuously on one part of the farm and hay and pasture (humus forming crops) on another part, it is but necessary to alternate the crops, thus improving the condition of the soil and the prospect of good yields on all parts of the farm.

Importance of Grass Crops.

In some instances, as in the case of grain farms, it has been necessary to increase the proportion of the farm sown to grass. The continuous cropping of grain practiced so many years has reduced the amount of vegetable matter in the soil and increased the amount of weeds until the crop yields are so low as to make grain growing unprofitable. On such farms it is undoubtedly profitable to increase quite largely the proportion of the farm sown to grass, even though there is but little use for the hay, owing to the desirable effect the grass will have in building up and cleaning the soil. There are few cases in which roughage thus grown cannot be put to some profitable use, either by increasing the amount of livestock kept on the farm or at least buying stock cattle or sheep to feed during the fall and winter.

Decreasing Acreage of Grain Does Not Necessarily Decrease Profits.

The net profit from an acre of wheat on run down soils is very small; consequently, decreasing the acreage of wheat under such conditions will not materially decrease the net profit of the farm.

TABLE XLII.—Showing Net Profit or Loss from Yields of Wheat.

Yield	Price (a)	Value per Acre	Cost of Production including Rent (b)	Net Profit or Loss
20	$ .638	$12.76	$ 7.89	$ +4.87
16	.638	10.21	7.89	+2.32
12	.638	7.66	7.89	— .23
10	.638	6.38	7.89	—1.51
8	.638	5.10	7.89	—2.79

(a) Average farm price December 1st for 10 years (1895-1904 inc.) as given by U. S. Dept. Year Book, 1904.
(b) Minnesota Bulletin No. 97, page 40.

From the above table it will be seen that as large a net profit is realized from one crop of twenty bushels per acre as from two crops of 16 bushels; and that a twelve bushel crop or less yields a net loss. It is a safe conclusion that seventy-five acres of grain each year on land growing a crop of clover every fourth year will yield a larger net profit than will one hundred acres sown to grain continuously.

A hay crop is one of the very cheapest crops to grow, as no extra preparation of the land or sowing is necessary, the grass seed being sown with the preceding grain crop. All the charges to be made against the grass crop are rent, cost of seed and harvesting. This is considerably lower than the cost of growing a crop of grain or corn, hence it is not necessary that the crop yield as large a gross product in order to return equivalent net profits. Where live stock is kept grass marketed as beef, mutton, pork or milk often makes a larger net return per acre than does grain.

In addition to whatever profits may be made from the grass crop, the first grain or corn crop following it will usually yield enough more than it would following a grain crop to net as large a profit as would two low yielding crops of grain.

Rotation Experiment.

With a view to demonstrating the value and practicability of the rotation of crops, and at the same time studying various systems of rotation, the Minnesota Experiment Station laid out in 1894, 44 one-tenth acre plots for such purposes. These plots were described as follows in Bulletin No. 40 of this station:

History of 44 Rotation Experiment Plots.

"In the spring of 1894 forty-four plots each two by eight rods, one-tenth acre, were laid off on fairly uniform land on the northeast corner of University Farm. The land is a medium heavy clay loam or slightly modified till soil of good fertility, naturally well underdrained and able to retain a fairly large amount of capillary moisture throughout periods of severe drought. The plots are in four series running east and west and containing eleven plots each, these running north and south. Between each series the ends of the plots are separated by alleys a rod wide, and between each pair of plots are alleys twelve feet wide, an alley two feet wide separating the two plots of the pair. This separates the plots and enables the teamster to reach all plots in using any machine without unnecessary tramping.

"The land on which these plots were laid out had grown oats in 1892, barley in 1893 and had been in clover and timothy meadow during a number of years. The land is not thought to be as uniform in quality as is desirable. Plots 1, 2, 3, and 4, series II, and plot 4, series III, are in a slight depression which we suppose gives them the advantage of more moisture in dry seasons and somewhat richer soil. Below is given a general statement of the plan of work.

"*Check or control plots.* Plots 1, 6 and 11 of each series are designated as check or control plots, thus giving twelve plots all seeded to the same practical rotation. These are in three rows, one extending along the east and one along the west end of all the series, and one through the middle, all running north and south. This plan distributes the control plots in such a manner that the yields or profits on any plot can be compared with the average from all twelve control plots or with the averages from the several control plots immediately surrounding it. On the twelve control plots the following plan of rotation has been instituted: wheat is sown the first year, and with this crop the land is seeded down by sowing with the spring wheat six pounds red clover and eight pounds timothy seed. The second and third years it is left to meadow, and the fourth year oats. The fifth and last year of the rotation corn is planted, and the land, previous to fall plowing the oats stubble for the corn, is given eight tons of barnyard manure per acre. Following the corn the wheat again begins the rotation of these same crops. These twelve control plots all being each year seeded to the same crop will give not only the average figures with which to compare the results of the different rotations, but will also give the range of variation or soil value of the plots in the field. These variations may prove very useful when summarizing the results of the experiments, and may show how great, yields and profits must differ to show a decided superiority of one crop of one rotation over another."

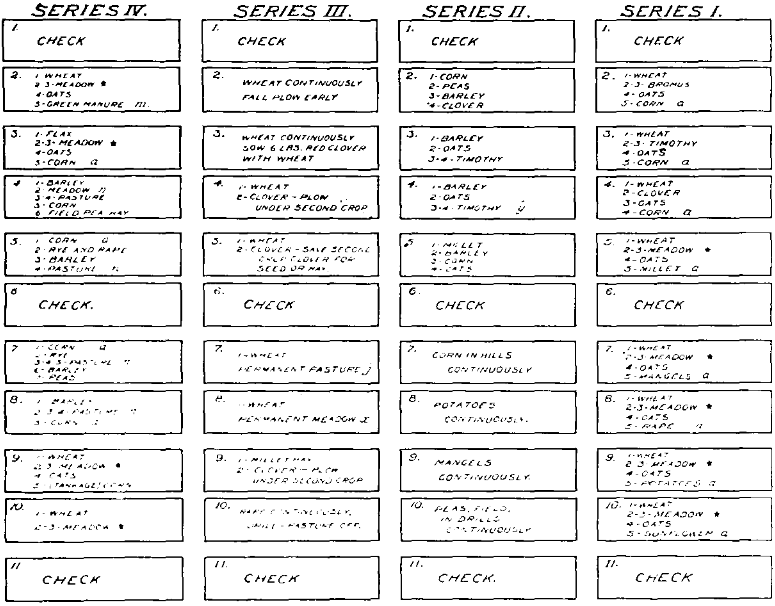


Fig. 12.—Showing arrangement of the 44 rotation plots, also system of cropping on each plot. The plots marked check plots, 1, 6 and 11, on each series, are cropped to the five year standard Control Rotation: first year, eight tons stable manure, corn; 2nd year, wheat; 3rd and 4th years, meadow (timothy and clover); 5th year, oats.

* Timothy 8 lbs., red clover 6 lbs.

a Eight tons stable manure per acre.

y Top dress timothy after mowing first hay crop.

j Red clover 3 lbs., timothy 4 lbs., red top 1 lb., Kentucky blue grass 7 lbs., orchard grass 3 lbs., brome grass 2 lbs., alsike 1 lb., white clover 1 lb.

x Red clover 4 lbs., alsike 1 lb., timothy 4 lbs., orchard grass 7 lbs., bromus 3 lbs.

m Plow under a crop of mixed oats and millet eartly in summer and later in fall a crop of rape.

n Timothy 8 lbs, red clover 4 lbs, alsike 1 lb.

The cut on Page 303 shows the arrangement of and the proposed rotation on each of the forty-four plots. The notes below give facts regarding grass mixtures, manuring and other special features of treatment. It will be seen from a study of this cut that a separate rotation was planned for each plot instead of using as many plots for each rotation as there are years in the rotation. This has been a saving of space which was necessary owing to a lack of land suitable for plot work, and these rotations are simply preliminary to more extensive work outlined to be carried out as soon as the land recently purchased by the University can be fitted for reliable plot work. These plots furnish a good introduction to the study of rotation ,and have been very helpful in outlining future work. Many of the results are so pronounced and there is so much harmony of results from groups of plots that these preliminary experiments give results of large value to Minnesota.

Record Not Completed.

As was expected, an occasional mistake or a failure to get a catch of grass has prevented carrying out exactly a few of the rotations. However, they have been followed closely enough to give much valuable data, as will be observed by studying the following tables. The rotation on all the check plots, (plots 1, 6 and 11 of each series) has been carried out exactly as planned.

These rotation plots have been of great value as actual demonstration plots to visitors at University Farm. Some thousands of farmers have observed them during the growing seasons, and it is believed that no one sees them without getting a much clearer conception of the real value and practicability of the rotation of crops. Simply to observe the growing crop on Series II, Plot 7, which grows corn continuously, and a crop of corn on any of the plots on which the crops are rotated is convincing evidence of the value of rotation. The difference is readily apparent during the entire growing season. To observe the hay crop on Series III, Plot 8, which is permanent meadow, and to compare it with any plot of hay on a rotation plot, convinces one of the value of rotation meadows over permanent meadows, on land that can be broken up and that will grow other crops.

Every plot on which any crop has been grown continuously has done very poorly, comparing it with other plots in rotation, as is shown by the tabulated results:

The Cash Value of Crops.

The plots being cropped differently the same crop does not appear on all the plots the same year. It is quite impossible to compare a yield of hay with a yield of grain unless both crops are converted to terms of cash. The object of these experiments is to determine the most profitable systems of cropping; hence it was found necessary in comparing results to establish an average farm price for all of the crops grown.

The average monthly prices of grain, for the ten years covered by this report, were obtained from the Minneapolis Chamber of Commerce reports, and from these averages reductions were made for freight, commission and elevator charges. The prices thus obtained were assumed to be the average farm prices. These prices were then compared with the December 1st farm prices given by the U. S. Department of Agriculture, and they compared so closely that it was deemed wise to use the Department prices for all products quoted in the year book.

TABLE XLIII.—The Farm Price of Farm Products December 1st each Year for the Years 1895-1904 inclusive, and Average for Ten Years (a).

Year	Wheat	Oats	Barley	Corn	Rye	Hay	Potatoes
1895	$ .44	$ .14	$ .24	$ 20	$ 28	$5 12	$ 14
1896	.68	.15	.20	.19	.30	3 79	.21
1897	.77	.19	.24	.24	37	4 50	31
1898	.54	.21	.33	.24	.38	3.70	25
1899	.55	.22	.31	.24	.42	4 35	25
1900	.63	.24	38	.29	.42	6 95	30
1901	.60	.34	.45	.45	.49	5 58	.67
1902	.61	.27	.37	.40	.43	5 36	31
1903	.69	.30	.37	.38	.45	6.61	61
1904	.87	.26	.42	.36	.64	5.51	29
Average 10 years	.638	.232	.331	.299	.418	5 15	.334

(a) Compiled from U. S. Dept. of Agr. Year Book for 1904.

The average prices for ten years as given above are the prices used in compiling the tables for this bulletin. As no prices were available for fodder corn and millet hay, the prices of $4.00 per ton for fodder corn and $5.15 per ton for millet hay were taken. These figures are based on the relative feeding value of these crops compared with mixed hay at $5.15 per ton.

The Dept. year books do not give the farm price of flax so this was arrived at as follows. The price reported by the Minneapolis Chamber of Commerce for 1900 to 1904 is $1.37¾. The price in Chicago for the same years was $1.38 9/16 or a difference of 13/16 cents. The average price for ten years (1895-1904) in Chicago is $1.21 5/16 deducting 13/16 the difference between Chicago and Minneapolis prices we get the average Minneapolis price of $1.20½. Deducting the average commission, storage and dockage charges leaves the average farm price for the ten years $1.094.

The price of pasturage at 25c. per 1,000 pounds live weight per week has been arbitrarily taken, as has also the price of $1.75 per ton for mangels and 75c. per bushel for peas.

The Standard Rotation on the Check Plots.

As shown by the chart on Page 303, on Plots 1, 6 and 11 of each series, a standard five year rotation was planned. This rotation has been carried out as planned and the results show this to be a very practical rotation. It has maintained the productivity of the soil both in yields and in money value.

Table XLIV gives the crops grown each year, the yield per acre and the cash value of the crop; also the average yield and cash value per acre for the whole ten years and for the last five years of the experiment.

The average yield in cash value per acre on the three check plots of each series is a fair basis with which to compare the other rotations in the same series.

XLIV.—Yields and Cash Value of Crops on Three Check Plots on each Series.

The following standard 5 yr. rotation was followed on each of the twelve check plots, first year wheat, second and third years grass, fourth year oats, and fifth year corn.. Eight tons of barnyard manure are applied per acre to the corn crop.

SERIES I.

	PLOT 1			PLOT 6			PLOT 11		
Year	Crop	Yield	Cash Value	Crop	Yield	Cash Value	Crop	Yield	Cash Value
1895	Wheat	31.5 bu.	$20.10	Wheat	27.0 bu.	$17.23	Wheat	27.4 bu.	$17.48
1896	Tim. Clo.	3.47T.	17.87	Tim. Clo.	1.4T.	7.21	Tim. Clo.	2.35T.	12.10
1897	" "	3.35T.	17.25	" "	3.2T.	16.48	" "	3.1 T.	15.96
1898	Oats	49.7 bu.	11.53	Oats	53.9 bu.	12.50	Oats	54.2 bu.	12.57
1899	Corn	58.3 bu.	17.43	Corn	44.4 bu.	13.28	Corn	47.2 bu.	14.11
1900	Wheat	23.4 bu.	14.93	Wheat	22.6 bu.	14.42	Wheat	22.6 bu.	14.42
1901	Tim. Clo.	3.25T.	16.74	Tim. Clo.	2.75T.	14.16	Tim. Clo.	2.35T.	12.10
1902	" "	2.15T.	11.07	" "	2.37T.	12.21	" "	1.6 T.	8.24
1903	Oats	65.6 bu.	15.22	Oats	60.9 bu.	14.13	Oats	63.7 bu.	14.78
1904	Corn	51.4 bu.	15.37	Corn	39.7 bu.	11.87	Corn	56.9 bu.	17.01
Average 1895-1904			15.75			13.35			13.88
Average 1900-1904			14.67			13.36			13.31

SERIES II.

	PLOT 1			PLOT 6			PLOT 11		
Year	Crop	Yield	Cash Value	Crop	Yield	Cash Value	Crop	Yield	Cash Value
1895	Wheat	34.0 bu.	$21.69	Wheat	25.4 bu.	$16.21	Wheat	26.8 bu.	$17.10
1896	Tim. Clo.	4.47T.	23.02	Tim. Clo.	2.4T.	12.36	Tim. Clo.	2.95T.	15.19
1897	" "	3.45T.	17.77	" "	3.17T.	16.33	" "	3.32T.	17.10
1898	Oats	49.8 bu.	11.55	Oats	58.4 bu.	13.55	Oats	53.9 bu.	12.50
1899	Corn	55.5 bu.	16.59	Corn	48.6 bu.	14.53	Corn	51.3 bu.	15.34
1900	Wheat	30.8 bu.	19.65	Wheat	25.5 bu.	16.27	Wheat	22.1 bu.	14.10
1901	Tim. Clo.	4.22T.	21.73	Tim. Clo.	2.5T.	12.88	Tim. Clo.	2.8 T.	14.42
1902	" "	2.75T.	14.16	" "	1.75T.	9.01	" "	1.8 T.	9.27
1903	Oats	63.7 bu.	14.78	Oats	62.1 bu.	14.41	Oats	63.7 bu.	14.78
1904	Corn	56.9 bu.	17.01	Corn	47.9 bu.	14.32	Corn	50.0 bu.	14.95
Average 1895-1904			17.79			13.99			14.47
Average 1900-1904			17.47			13.38			13.50

TABLE XLIV—(Continued).

SERIES III.

	PLOT 1			PLOT 6			PLOT 11		
Year	Crop	Yield	Cash Value	Crop	Yield	Cash Value	Crop	Yield	Cash Value
1895	Wheat	26 8 bu	$17 10	Wheat	27 4 bu	$17.48	Wheat	29 4 bu	$18.76
1896	Tim Clo	3 22T	16 58	Tim Clo	2.85T	14.68	Tim Clo	2.92T	15.04
1897	" "	3.62T.	18.64	" "	3 1 T	15 97	" "	3.15T	16.22
1898	Wheat	21.8 bu.	13.91	Oats	60 4 bu	14.01	Oats	61 8 bu	14.34
1899	Corn	57.6 bu.	17.22	Corn	50.6 bu	15.13	Corn	58.3 bu.	17.43
1900	Wheat	23.3 bu.	14.87	Wheat	24.0 bu.	15.31	Wheat	28.6 bu.	18.25
1901	Tim. Clo.	3.2 T.	16.48	Tim. Clo.	3.0T.	15.45	Tim. Clo.	2.25T.	11.59
1902	" "	2.1 T	10.82	" "	1.7 T.	8.76	" "	2.2 T.	11.33
1903	Oats	59.0 bu.	13.69	Oats	71.2 bu.	16.52	Oats	70.0 bu.	16.24
1904	Corn	58.3 bu.	17.43	Corn	51.2 bu.	15.31	Corn	58.6 bu.	17.52
Average 1895-1904			15.67			14.86			15.67
Average 1900-1904			14.66			14 27			14.99

SERIES IV.

	PLOT 1			PLOT 6			PLOT 11		
Year	Crop	Yield	Cash Value	Crop	Yield	Cash Value	Crop	Yield	Cash Value
1895	Wheat	28.1 bu.	$17.93	Wheat	23.7 bu.	$15.12	Wheat	25.7 bu.	$16.40
1896	Tim. Clo.	3.0 T.	15.45	Tim. Clo.	2.17T.	11.18	Tim. Clo.	1.74T.	8.96
1897	" "	3.4 T.	17.51	" "	3.15T.	16.22	" "	2.95T.	15.19
1898	Oats	43.4 bu.	10.07	Oats	52.9 bu.	12.27	Oats	54.5 bu.	12.64
1899	Corn	51.3 bu.	15.34	Corn	46.5 bu.	13.90	Corn	63.8 bu.	19.08
1900	Wheat	24.3 bu.	15.50	Wheat	20.3 bu.	12.95	Wheat	20.6 bu.	13.14
1901	Tim. Clo.	3.45T.	17.77	Tim. Clo.	2.1T.	10.82	Tim. Clo.	2.7 T.	13.90
1902	" "	2.05T.	10.56	" "	1.5 T.	7.72	" "	1.8 T.	9.27
1903	Oats	51 2 bu.	11.88	Oats	61.2 bu.	14 20	Oats	60.0 bu.	13.92
1904	Corn	54.0 bu.	16.15	Corn	47.5 bu.	14.20	Corn	48.8 bu.	14.59
Average 1895-1904			14.82			12.86			13 71
Average 1900-1904			14 37			11 98			12.96

TABLE XLV.—Rotations Compared with Standard Rotation.

SERIES I.

	PLOTS 1-6-11			PLOT 2			PLOT 3		
Rotation	Corn; Wheat; Timothy, Clover Meadow; Timothy Clover Meadow; Oats.			Corn; Wheat. Bromus Meadow; Bromus Meadow; Oats.			Corn; Wheat; Timothy Meadow; Timothy Meadow; Oats;		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	28.6 bu.	$18 25	Wheat	29.2 bu.	$18.63	Wheat	28.2 bu.	$17.99
1896	Tim. Clo.	2.41T.	12.36	Bromus	.75T.	3.86	Timothy	1.85T.	9.53
1897	" "	3.22T.	16.58	Oats	29.7 bu.	6.89	"	1.42T.	7.31
1898	Oats	52.6 bu.	12.20	Oats	65.4 bu.	15.17	Oats	65.3 bu.	15.15
1899	Corn	49.9 bu.	14.92	Corn	52.7 bu.	15.76	Corn	49.3 bu.	14.74
1900	Wheat	22 9 bu.	14.61	Wheat	22.5 bu.	14.36	Wheat	21.6 bu.	13.78
1901	Tim. Clo.	2.78T.	14.33	Bromus	1.35T.	6.95	Timothy	1.00T.	5.15
1902	" "	2.04T	10.51	"	1.92T.	9.89	"	1.15T.	5.92
1903	Oats	63 4 bu.	14.71	Oats	56.0 bu.	12.99	Oats	59.3 bu.	13.76
1904	Corn	49.3 bu.	14.75	Corn	44.4 bu.	13.39	Corn	65.2 bu.	19.49
10 yr Average 1895-1904.			14.32			11.79			12.28
5 yr Average 1900-1904.			13.78			11.51			11.62

	PLOT 4			PLOT 5			PLOT 7		
Rotation	Corn; Wheat; Clover Meadow; Clover Meadow; Oats			Millet; Wheat: Timothy Clover Meadow; Timothy Clover Meadow; Oats.			Mangels; Wheat; Timothy Clover Meadow; Timothy Clover Meadow; Oats.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	30.3 bu.	$19.33	Wheat	27.1 bu.	$17.29	Wheat	24.2 bu.	$15.44
1896	Meadow	2.15T.	11.07	Tim. Clo.	3.37T.	17.36	Tim. Clo.	2.2 T.	11.33
1897	Oats	26.3 bu.	6.10	" "	3.27T.	16.84	" "	2.77T.	14 27
1898	Corn	65.2 bu.	19.49	Oats	50.3 bu.	11.67	Oats	49.6 bu.	11.51
1899	Wheat	30.5 bu.	19.46	Millet	3.00T.	15.45	Mangels	10.8 T.	18.90
1900	"	24.6 bu.	15.69	Wheat	26.6 bu.	16.97	Wheat	18.0 bu.	11.48
1901	Oats	67.2 bu.	15.59	Tim. Clo.	3.05T.	15.71	Tim. Clo.	2.05T.	10.56
1902	Corn	wt. lost		" "	2.05T	10.56	" "	1.6 T.	8.24
1903	Wheat	35.6 bu.	22.71	Oats	76.8 bu.	17.82	Oats	61.5 bu.	14.27
1904	Clover	4.75T.	24.46	Millet	2.25T.	11.59	Mangels	16.0 T.	28.00
10 yr. Average 1895-1904,			15.39			15.13			14.40
5 yr. Average 1900-1904,			15.69			14.53			14.51

TABLE XLV—(Continued).

	PLOT 8			PLOT 9			PLOT 10		
	Rotation: Rape: Wheat: Timothy Clover Meadow: Timothy Clover Meadow: Oats			Potatoes, Wheat: Timothy Clover Meadow: Timothy Clover Meadow, Oats.			Sunflowers; Wheat; Timothy Clover Meadow: Timothy Clover Meadow: Oats.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	25.4 bu.	$16.21	Wheat	25.9 bu.	$16.52	Wheat	26.5 bu.	$16.91
1896	Tim. Clo.	2 42T.	12.46	Tim. Clo.	2.3T.	11.84	Tim. Clo.	2.4 T.	12.36
1897	" "	2.67T.	13.75	" "	2.7T.	13.90	" "	2.6 T.	13.39
1898	Oats	55 1 bu.	12.78	Oats	54.2 bu	12.57	Oats	52.2 bu.	13.50
1899	Rape	——	——	Potato	21.0 bu	7 01	Sunflow'rs	1.4 T	——
1900	Wheat	14 0 bu.	8 93	Wheat	29 3 bu	18 69	Wheat	19 1 bu.	12.19
1901	Tim Clo.	2.3 T.	11 84	Tim. Clo	2.2T.	11 33	Tim Clo	2 0 T	10 30
1902	" "	1 82T.	9 37	"	1 5T	7 72	"	1.65T	8.50
1903	Oats	60 3 bu.	13 99	Oats	60 3 bu	13 99	Oats	60 0 bu.	13.92
1904	Rape	——	——	Potato	87 1 bu	29 09	Sunflow'rs	——	——
*Average 1895-1904.			12 42	Average 1895-1904.		14 27	Average 1895-1904.		12.63
*Average 1900 1904.			11.03	Average 1900-1904		16 17	Average 1900-1904.		11.23

* Averages 8 and 4 years respectively.

Series I.

Table No. XLV gives in the upper left hand corner averages of the three check plots 1, 6 and 11 of this series. The average yield in money value per acre of these three plots is $14.32. This serves as a very reliable comparison with the other plots since the three check plots are distributed over the series. All of the rotations on this series would naturally be expected to give good results since they all provide for the maintenance of the vegetable matter by growing grass crops and by the application of barnyard manure.

It was planned that all these plots be cropped under the five year rotation system, each plot varying only in one respect from the three check plots.

Plot 2. The rotation on plot 2 varies from the rotation on the three check plots by having bromus alone in place of timothy and clover. The results from this plot are not quite so good as from the average on the check plots, which would indicate that the bromus is not as desirable a grass crop for a short rotation as is timothy and clover. A comparison of the yields of bromus on this plot with the yields of timothy and clover for the three check plots shows that the first seeding to bromus did not catch well. In fact the crop was so poor that it was plowed up the second year rather than to leave it. The second seeding of bromus in 1901 shows a rather poor stand. It gave a yield of 1.35 tons compared with an average yield of 2.78 tons of timothy and clover on the three check plots.

Plot 3. The rotation on plot 3 varies from the standard rotation by being seeded to timothy alone rather than timothy and clover. The yields of hay produced on this plot were considerably below the average yields of hay on the check plots, which accounts for the low average cash value of the product. The yields of grain following the timothy meadow are as good or a little better than the yields following the timothy and clover meadow in the standard rotation.

Plot 4. Plot 4 was planned for a five year rotation with clover alone in place of timothy and clover in the standard rotation. Owing to the fact that it is impossible to keep clover more than one year when two crops are taken, the rotation has naturally been shortened to four years, the clover having produced a crop but one year. Excellent results have been obtained from this rotation as shown by the large yield and money value per acre. Shortening the rotation to four years and manuring the corn crop each time the plot is planted to corn, increases the amount of manure applied since the plot receives eight tons of manure every fourth year instead of every fifth year. It would not be safe, however, to conclude that this is a more valuable rotation than the five year rotation, because the cost of operating the farm under this system of cropping would be greater than under the five year rotation. As it costs more to grow a grain or corn crop than to grow a grass crop, the actual net yield in money value per acre from plot 4 is practically the same as that obtained on the three check plots.

Plot 5. The rotation on plot 5 varies from the standard rotation by having millet in place of the corn crop. Millet may very properly take the place of corn as a cleaning crop, since it is sown late in the spring giving a chance to destroy many weeds before seeding. The crop grows very rapidly and thick, thus giving very little opportunity for weeds to grow. Millet or barley might well be used in a rotation to replace corn where corn does not do well.

Plot 7. The rotation on plot 7 varies from the standard rotation by the sowing of mangels in place of corn. The yield in money value per acre is practically the same as from the standard rotation, but the net profit from such a rotation would be much less than from the standard rotation owing to the fact that it costs much more to grow a crop of mangels than to grow a crop of corn. The yields of mangels obained from this rotation are not sufficient to cover the cost of production. It is evident that mangels are harder on the soil than is corn from the yields of wheat obtained from this rotation, which follows the mangels while in the standard rotation wheat follows corn. This does not indicate that mangels are an unprofitable crop to grow, but that a five year rotation manured eight tons per acre once in five years is not a good rotation for mangels.

Plot 8. The rotation on plot 8 varies from the standard rotation by having rape in place of corn. Rape is a fairly good forage crop, but is much better adapted to use as a catch crop than as a regular crop. In this particular case no use could be made of the rape—hence no yield or value of crop was obtained.

Plot 9. The rotation on plot 9 varies from the standard rotation, having potatoes in the place of corn. This rotation has given very satisfactory results except in the yield of potatoes. The yields of potatoes obtained are not sufficient to pay for cost of production. Hence, if the cost of production were deducted, it would not compare favorably with the standard.

Plot 10. Plot 10 varies from the standard rotation, having sunflowers in place of corn. As there is no basis on which to establish a value for this crop it has been left out. The other crops in this rotation have given fair returns.

SERIES II.

Table XLVI gives in the upper left hand corner the average yields and cash values of the crops produced on the three check plots of this series. The average cash value of the crops for ten years is $15.41. This furnishes a fair basis for comparison of the rotations on the other plots.

Plot 2. A four year rotation was planned for plot 2 consisting of corn, peas, barley and clover. This plot has given very satisfactory results as shown by the average cash value of the product which is $14.56, and is very likely a practical rotation where peas are a profitable crop. It is probable that peas will make a profitable crop whereever corn does not do well and where reasonably good crops of peas can be grown.

Plot 3 *and* 4. A four year rotation was planned for these two plots consisting of barley, oats and timothy two years. The only difference in the plots is that plot 4 is top dressed each year after the first crop of hay is cut. No appreciable difference is shown in the yields of these two plots.

Plot 5. Plot 5 has done rather better than would be expected from such a rotation. It is a rotation in one sense of the word—that is, the crops are alternated, but no provision is made for keeping up the humus supply. The yields show a tendency to gradually decrease, and will undoubtedly continue to decrease as the experiment continues. Such a system of cropping should not be confused with a practical rotation. Comparing the rotation on this plot with Plot 2, Series III which grows wheat continu-

TABLE XLVI.—Rotations Compared with Standard Rotation.

SERIES II.

PLOTS 1-6-11.				PLOT 2			PLOT 3		
Rotation: Corn; Wheat; Timothy Clover Meadow; Timothy Clover Meadow; Oats.				Rotation: Corn; Peas; Barley; Clover.			Rotation: Barley; Oats; Timothy Meadow; Timothy Meadow.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	28.7 bu.	$18.33	Peas	20.83 bu.	$15.62	Oats	73.5 bu.	$17.05
1896	Tim. Clo.	3.27T.	16.86	Barley	47.08 bu.	15.58	Timothy	2.1 T.	10.82
1897	" "	3.31T.	17.07	Corn	44.4 bu.	13.28	"	1.97 T.	10.15
1898	Oats	54.0 bu.	12.53	Peas	28.5 bu.	21.38	Barley	54.4 bu.	18.01
1899	Corn	51.8 bu.	15.49	Peas	27.5 bu.	20.62	Oats	54.6 bu.	12.67
1900	Wheat	26.1 bu.	16.67	Barley	22.9 bu.	7.18	Timothy	1.25 T.	6.44
1901	Tim Clo.	3.17T.	16.31	Red Clo.	1.92 T.	9.89	"	1.65 T.	8.50
1902	" "	2.10T.	10.81	Corn	Wt. lost	——	Barley	43.7 bu.	14.46
1903	Oats	63.2 bu.	14.66	Peas	"	——	Oats	71.5 bu.	16.59
1904	Corn	51.6 bu.	15.43	Barley	41.2 bu.	13.63	Timothy	3.6 bu.	18.54
10 year Average 1895-1904			15.41			14.82			13.32
5 year Average 1900-1904			14.78			10.37			12.70

PLOT 4				PLOT 5			PLOT 7		
Rotation: Barley; Oats; Timothy Meadow; Timothy Meadow.				Rotation: Millet; Barley; Corn; Oats.			Rotation: Corn in hills continuously.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	77.3 bu.	$17.93	Barley	52.0 bu.	$17.21	Corn	29.3 bu.	$ 8.76
1896	Timothy	1.77 T.	9.12	Corn	52.8 bu.	15.79	"	31.9 "	9.54
1897	"	1.95 T.	10.04	Oats	32.8 bu.	7 61	"	29.9 "	8.94
1898	Barley	53.7 bu.	17.77	Millet	2.5 T.	12.87	"	27.7 "	8.28
1899	Oats	51.7 bu.	11.99	Barley	48.1 bu.	15.92	"	20.8 "	6.22
1900	Timothy	.5 T.	2.58	Corn	45.8 bu.	13.69	"	37.5 "	11.21
1901	"	1.55 T.	7.98	Oats	70.3 bu.	16.31	"	13.9 "	4.16
1902	Barley	45.8 bu.	15.15	Millet	.82 T.	4.32	"	Wt. lost	——
1903	Oats	68.4 bu.	15.87	Barley	34.3 bu.	11.35	"	23.6 bu.	7.06
1904	Timothy	3.57 T.	18 39	Corn	44.0 bu.	13.16	"	11.1 "	3.32
10 year Average 1895-1904,			12.68			12.82			6.75
5 year Average 1900-1904,			11.90			11.77			5.15

TABLE XLVI—(Continued).

	PLOT 8			PLOT 9			PLOT 10		
	Rotation: Potatoes, continuously.			Rotation: Mangels continuously.			Rotation· Field Peas, sown with drill continuously.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Potatoes	146.66 b.	$48.98	Mangels	11.1 T.	$19.42	Peas	15 5 bu.	$11.62
1896	"	11.6 b.	3.87	"	2.0 "	3.50	"	21 83 "	16.37
1897	"	86.6 b.	28.92	"	7 25 "	12.69	"	2.33 "	1.75
1898	"	———	———	"	———	———	"	15.8 "	11.85
1899	"	58.3 b.	19.47	"	13.11 "	22.94	"	———	———
1900	"	43.8 b.	14.63	"	9.85 "	17.24	"	14.5 "	10.88
1901	"	———	———	"	4.25 "	7.44	"	———	———
1902	"	———	———	"	5.45 "	9.54	"	7.16 "	5.37
1903	"	88.0 b.	29.39	"	6 6 "	11.55	"	———	———
1904	"	65.5 b.	21.88	"	4.1 "	7.18	"	———	———
7 year Average			23.88	9 year Average,		12.39	6 year Average,		9.64
3 year Average			21.97	5 year Average,		10 59	2 year Average,		8.12

ously) as nearly as the yields of different crops may be compared, shows, it is believed, the value of the classification of crops as given on Page 292. The crops on plot 5, series II are all humus consuming crops, the same as is wheat on plot 2, series III, and the fact that they have been changed about does not seem to maintain the soil in a higher state of productivity than does continuous wheat cropping.

Plot 7. The low yields of corn on plot 7 may be a surprise to many. It is generally believed that corn has a beneficial effect on the soil. It is well known that usually after a crop of corn a larger yield of grain is secured. So one might easily infer that corn is a beneficial crop and be correspondingly surprised at the low yields obtained in this experiment. It will be observed also, that this plot gives poorer returns than plot 2, Series III, on which wheat has been grown continuously. This, too, is contrary to what might generally be expected, since wheat has the reputation of being hard on the land while corn is believed to be beneficial.

Corn is beneficial to the soil in many ways. The frequent cultivation given corn maintains during a portion of the year an effective surface mulch which aids very much in conserving moisture. The cultivation, in aerating the soil, and in conserving moisture, naturally stimulates decomposition and maintains quite effectively the conditions favorable for chemical and bacterial action. The large yields of grain usually obtained following a crop of corn show that this crop prepares the soil for other crops. The stubble and corn roots return very little vegetable matter to the soil. When corn is grown year after year on the same field the vegetable matter supply is rapidly broken down and depleted; much more rapidly than is the case with continued wheat growing, for the cultivation of the corn stimulates decomposition while in a wheat field the decomposition is less rapid.

Plot 7 has always been planted at the same time, with the same quality of seed, and has received the same cultivation as have other corn plots in the rotations, yet it has failed to give as good results. Comparing the yields of corn on this plot with the check plot beside it, plot 6, for the years the check plot produced corn, the following results are obtained:

TABLE XLVII.—Comparative Yields of Corn.

	1899	1904	Ave 2 years
Series II Plot 6, 5 yr. rotation	48.6 bu	47.9 bu	48.2 bu.
Series II Plot 7, corn continuously	20.8 bu	11.1 bu	16.0 bu.
		Gain	32.2 bu.

The yields of potatoes on plot 8 and of mangels on plot 9 tell the same story. The yields have shown a gradual decrease which is due, it is believed, to the rapid depletion of vegetable matter favored by cultivation. A cultivated crop has about the same effect on the soil as summer fallowing.

Though it is plainly shown from table XLVI that corn continuously is hard on the soil, yet a study of the yields of other crops following corn in rotation show it to be a valuable crop in a rotation system where the vegetable matter is kept up by manure and grass crops. The growing of corn is also conducive to the keeping of livestock. This results in more manure to add to the fields. There are few of the common field crops that can be more profitably grown on a portion of the average farm in Minnesota, than corn, when manure or grass crops, or both, are used to keep up the supply of vegetable matter.

Corn has been grown successfully for several years in succession on other fields at this station, but the humus supply has been maintained by several dressings of barnyard manure.

Plots 8 *and* 9. Plots 8 and 9 have given very poor yields which can be explained in the same way in which the low yields of corn on plot 7 are explained, that is the cultivation year after year has depleted the soil of vegetable matter until it can no longer be kept in good physical condition. The high cash value for the crop on plot 8 must not be misinterpreted since the cost of production is very high for this crop.

Plot 10. Plot 10 has grown peas continuously for ten years and though the yields shown are low and several crops have been lost by unfavorable weather conditions the plot is still in fairly good condition.

Series III.

Table XLVIII gives in the upper left hand corner the average yields and cash values of the crops produced on the three check plots of this series, the average cash value of the crops for ten years is $15.40. This furnishes a fair basis for comparison of the rotations on the other plots of this series.

Plot 2. The cash value of crops grown on plot 2, which grows wheat continuously, is considerably below

TABLE XLVIII.—Rotations Compared with Standard Rotation.

SERIES III.

PLOTS 1-6-11				PLOT 2			PLOT 3		
Rotation: Corn; Wheat; Grass. Grass; Oats.				Rotation: Wheat continuously, plowed in early fall.			Rotation: Wheat continuously with 6 lbs. Red Clover Seed per acre.		
Year	Crop	Yield	Value	Crop	Yield	Value	Wheat	Yield	Value
1895	Wheat	27.9 bu.	$17.78	Wheat	24.7 bu.	$15.76	"	25.6 bu.	$16.33
1896	Tim. Clo.	3.0 T.	15.43	"	14.7 "	9.35	"	20.0 "	12.76
1897	Tim. Clo.	3.29 T.	16.95	"	17.8 "	11.36	"	22.2 "	14.16
1898	Oats	48.0 bu.	14.09	"	21.4 "	13.65	"	23.5 "	14.99
1899	Corn	55.5 bu.	16.59	"	22.5 "	14.36	"	24.0 "	15.31
1900	Wheat	25.3 bu.	16.14	"	14.5 "	9.25	"	19.8 "	12.63
1901	Tim. Clo.	2.82 T.	14.51	"	16.0 "	10.21	"	11.3 "	7.21
1902	Tim. Clo.	2.0 T.	10.30	"	17.0 "	10.85	"	15.0 "	9.57
1903	Oats	67.67 bu	15.48	"	16.3 "	10.40	"	24.1 "	15.38
1904	Corn	56.03 bu	16.75	"	20.8 "	13.27	"	32.5 "	20.74
10 year Average 1895-1904,			15 40			11.85			13.91
5 year Average 1900-1904,			14.64			10.80			13.11

PLOT 4				PLOT 5			PLOT 7		
Rotation: Wheat: Clover; second crop plowed under.				Rotation: Wheat; Clover; second crop saved for hay.			Rotation: Permanent pasture, Timothy and Clover.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	28.2 bu.	$17.99	Wheat	30.0 bu.	$19.14	Wheat	25.3 bu.	$16.14
1896	Clover	1.42 T.	7.31	Red Clo.	2.24 T.	11.54	Pasture	1.92 T.	9.89
1897	Wheat	20.0 bu.	12.76	Wheat	20.5 bu.	13.08	"	1.17 "	6.03
1898	"	24.3 "	15.50	"	26.7 "	17.03	Wheat	19.8 bu.	12.63
1899	"	24.2 "	15.44	"	24.7 "	15.76	Pasture	data lost	———
1900	"	20.8 "	13.27	"	26.1 "	16.65	"	" "	———
1901	Clover	1.12 T	5.77	Clover	2.57 T.	13.24	"	162.3 days	5.80
1902	Wheat	18.8 bu.	11.99	Wheat	22.0 bu.	14.04	"	1.32 T.	6.80
1903	Clover	5.5 T.	28.32	Clover	5.8 T.	29.87	"	216d & 1.5T	15.44
1904	Wheat	data lost	———	Wheat	data lost	———	"	247.5 days	8.84
9 years Average,			14.26	9 years Average		16.71	8 years Average		10.20
4 years Average,			14.84	4 years Average		18.45	4 years Average		9.22

TABLE XLVIII—(Continued).

PLOT 8				PLOT 9			PLOT 10		
Rotation: Permanent Meadow, Timothy and Clover.				Rotation: Millet. Hay. Clover, second crop plowed under			Rotation: Rape in drills continuously. pastured off		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	27.4 bu.	$17.48	Millet	2.72 T.	$12.24	Rape	11 1 T	....
1896	Meadow	1.87 T.	9.63	"	1.75 "	7.88	"	7 3 "	....
1897	"	2.47 "	12.72	"	Failure	....	"	1 6 "	....
1898	Wheat	21.0 bu.	13.40	"	2.0 T.	9.00	"	....	....
1899	Pasture	data lost	....	"	1.45 "	6 52	"	....	....
1900	Meadow	.9 T.	4.64	"	Failure	....	"	....	....
1901	"	.95 "	4.89	"	1.22 T.	5.49	"	73 days	$ 2 61
1902	"	1.27 "	6.54	"	1.7 "	7.65	"	....	....
1903	"	3.65 "	18.80	"	Failure	....	"	192 days	6 86
1904	"	1.95 "	10.04	"	1 5 T	6.75	"	225 days	8 04
9 years Average			10.90	10 years Average		5 55			
5 years Average			8.98	5 years Average		3.98	3 years Average		5 84

that on plot 1, or on an average of the three check plots in this series. However the yields have held up much better than might have been expected from the practice of growing wheat continuously. The early fall plowing and good tillage have helped to keep the soil in fair condition. However, the yields of wheat in comparison to the yields on plots that are rotated are showing a gradual decrease. No other result can be expected from such practice.

Plot 3. Many grain farmers are so situated, or at least feel that they are, as to be unable to make use of enough pasture and meadow land or to produce enough manure on their farms to maintain the humus supply in their soils. The results obtained on plot 3 illustrate a practice which may be profitably followed under such conditions.

Plots 2 and 3 have received exactly the same treatment as to seed, seeding and tillage, except on plot 3 red clover seed has been sown at the rate of six pounds per acre each spring with the wheat, and the resulting crop of clover plowed under in the fall. The yields of wheat on the two plots show an increased yield on plot 3 of 3.24 bu. per acre. The cost of that $3\frac{1}{4}$ bu. per year has been six pounds of clover seed or 90c., leaving a net profit of $1.17. While it is undoubtedly impossible to maintain the productivity of the soil in this way indefinitely and grow grain continuously, it is nevertheless a feasible proposition for the farmer who is unable to more effectively maintain the productivity by a well organized rotation. Even where rotation is practiced and where a large amount of meadow and pasture is not needed, the acreage of grain can be increased and the acreage of grass decreased if two to six pounds of clover seed per acre are sown with each grain crop. The increased yield will more than pay for the clover seed, and the improvement of the land will be a clear profit. Sowing clover seed each year with the grain will gradually inoculate the soil with clover bacteria, so that when a stand of clover and timothy for meadow or pasture is desired, the chances of obtaining it are greatly increased.

Clover sown in corn at the last cultivation has given good results. The crop may be pastured off in the fall or plowed under to increase the humus supply in the soil.

Weediness.

One of the greatest difficulties encountered by extensive wheat growers is weeds. Wild oats especially are troublesome in grain sections. This weed has very nearly taken possession of many grain fields and continues to get worse year after year. Nothing else can be expected so long as wheat or oats are grown continuously. The wild oats ripen and drop many of their seeds before the grain is cut, thus reseeding the field for the next year.

Plots 2 and 3 in this series became seeded with wild oats a few years ago, probably from the droppings of teams at work on the plots. Although these wild oats have been pulled by hand several times they are still quite abundant. Plot 1, which is separated from plot 2 only by a two-foot alley is completely free from wild oats. The wild oats are unable to get a start on plot 1, for the corn crop once in five years cleans them out and the two years of grass also gives them no show to seed, the grass crops being cut before the wild oats can seed and most of the seeds buried by the sod lose their power to grow.

VALUE OF CLOVER.

Plots 4 and 5. The value of clover is shown by the yields on plots 4 and 5. These plots, though they have received no manure nor have they grown a cultivated crop, have maintained a high state of productivity. Probably such a rotation is not practical for many farms as one-half of the farm would be producing clover. However, this rotation as actually carried out, has produced clover but three times in ten years, making an average of three-tenths of the farm in clover and seven-tenths in wheat, which is not an unreasonable proportion. The productive capacity of many of the old grain fields in the state would be greatly increased if they were sown to clover every few years. This is especially true if the clover can be fed on the farm and the manure resulting therefrom applied to the fields. The value of clover for a cleaning crop is here demonstrated. Plots 3 and 4 are separated only by a two-foot alley; plot 4 is comparatively free of weeds while plot 3 which grows wheat continuously is quite badly infested with wild oats.

Plots 7 and 8. Plots 7 and 8 on which grass has been grown continuously, have given very poor results as compared to hay grown in rotation. The yields of pasturage on plot 7 show up very well for the past couple of years, but from careful observation and from the yields of hay obtained on plot 8, it is quite evident that these pasturing results are not accurate. In fact, it is quite impossible to get accurate results from pasturing small plots. This is one thing of value that has been determined from the pasturing experiments carried out in these rotations. The tramping and discontent of the animals, when confined too closely, are features that must be overcome by using larger plots.

Millet as a Nurse Crop.

Plot 9. Plot 9, on which it was intended to follow a two-year rotation of millet and clover, has failed so far to produce a crop of clover, which is due no doubt to several causes. Millet is seeded late in the spring, which is not a favorable time for sowing clover seed. Millet also is a very rank growing crop, consequently shading the ground quite thoroughly, and this plot has never appeared to be in good physical condition. All of these causes together have prevented getting a stand of clover. A good crop of clover would greatly improve the condition of this plot and if a crop is once secured, it is quite possible that this rotation might then be carried out successfully. Millet and clover together do not make a very desirable rotation, but if it is possible to get a catch of grass by sowing the seed with millet, this practice might be valuable in case of failure in a regular rotation to get a stand of grass. In such case the field could be sown to millet and grass seed. The millet would furnish the hay crop to take the place of the grass that failed, and the field would be seeded down for the next year.

The fact that millet is often used for hay leads to its being used in some cases in place of such grass crops as timothy and clover. Millet being an annual it has about the same effect on the soil as a grain crop. That is, it does not develop a heavy root system as do such biennials or perennials as timothy and clover, hence it does not increase the amount of vegetable matter in the soil. Millet should be grown for hay only as a catch crop or where the biennial and perennial grasses cannot be grown.

Rape.

Plot 10. Plot 10, as will be observed, has grown rape continuously, and though very poor results are shown from this plot, very fair crops have been grown each year. The main value of rape is as a catch crop or for an annual pasture crop for hogs or sheep. One of the reasons why poor results were obtained on this plot is that it was not convenient to pasture the plot with either hogs or sheep. The cattle used were not as a rule used to eating rape and usually tramped it down before taking it.

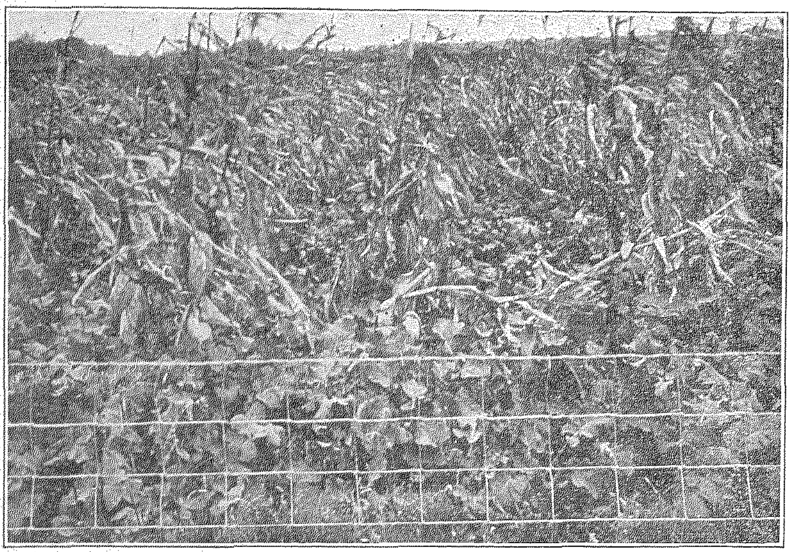


Fig. 13.—Rape in corn Sept. 15th. Three lbs. of rape sown just before the corn was cultivated the last time.—Photo by H. D. Ayer.

Rape may be sown at any season of the year, and usually in six to eight weeks is from ten to eighteen inches high. The seed is cheap, costing from 5c. to 6c. per pound, and two to four pounds is ample for an acre. It has proved on other fields a valuable crop for hog pasture, and on many farms it is sown with the grain in the spring, one to two pounds per acre, to furnish fall feed for sheep or other stock. Several different times at the station, three pounds of rape per acre has been sown in the corn,—just before the last cultivation, and has given a great quantity of fall feed at a very small cost, besides preventing very largely the growth of weeds in the corn during the fall.

TABLE XLIX.—Rotations Compared with Standard Rotation.

SERIES IV.

	PLOTS 1-6-11			PLOT 2			PLOT 3		
	Rotation: Corn; Wheat; Grass; Grass, Oats.			Rotation: Wheat; Timothy; Clover Meadow; Timothy Clover Meadow; Oats; Green Manure			Rotation: Flax; Timothy Clover Meadow; Timothy Clover Meadow; Oats; Corn		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Wheat	25.8 bu.	$16.48	Wheat	27.9 bu.	$17.80	Flax	9.28 bu.	$10.15
1896	Tim. Clo.	2.30 T.	11.86	Tim. Clo.	2.8 T.	14.42	Tim. Clo.	3.05 T.	15.71
1897	" "	3.17 "	16.31	" "	3.27 T.	16.84	" "	3.7 "	19.06
1898	Oats	50.3 bu.	11.66	Oats	55.7 bu.	12.92	Oats	60.7 bu.	14.08
1899	Corn	53.9 "	16.11	Oats & Mil	....	....	Corn	53.4 "	15.97
1900	Wheat	21.7 "	13.86	Wheat	21.6 bu.	13.78	Flax	7.4 "	8.10
1901	Tim. Clo.	2.75 T.	14.16	Tim. Clo.	2.8 T.	14.42	Tim. Clo.	3.7 T.	19.06
1902	" "	1.78 "	9.18	" "	1.6 "	8.24	" "	2.4 "	12.36
1903	Oats	57.5 bu.	13.33	Oats	56.2 bu.	13.04	Oats	69.6 bu.	16.15
1904	Corn	50.1 "	14.98	Oats	30.6 bu.	7.10	Corn	....	....
	10 years Average		13.79	10 years Average		11.86	9 years Average		14.52
	5 years Average		13.10	5 years Average		11.31	4 years Average		13.92

	PLOT 4			PLOT 5			PLOT 7		
	Rotation: Barley; Timothy Clover Meadow; Pasture; Pasture; Corn; Field Peas for Hay.			Rotation: Corn, Rye & Rape; Barley, Timothy & Clover; Pasture.			Rotation: Corn; Rye; Pasture; Pasture; Pasture; Barley; Peas.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Barley	47.9 bu	$15.85	Fall Rye	43.1 bu	$18.02	Fall Rye	43.1 bu	$18.02
1896	Meadow	3.8 T	19.57	Barley	39.8 "	12.78	" "	....	....
1897	Pasture	3.45 "	17.77	Meadow	2.51 T	12.93	Meadow	3.0 T	15.45
1898	"	2.5 "	12.88	"	2.5 "	12.88	"	2.25 "	11.59
1899	Corn	48.6 bu	14.53	"	....	....	Barley	41.2 bu	13.63
1900	Pea Hay	1.6 T	8.00	Fod.Corn	3.55 "	14.20	Peas	18.7 "	14.02
1901	Wheat	14.5 bu	9.25	Rye	18.6 bu	7.77	Corn	....	....
1902	Oat Hay	4.7 T	16.00	Barley	50.1 "	16.08	Oat Hay	4.2 T	16.80
1903	Meadow	2.45 "	12.62	Meadow	3.6 T	18.54	Meadow	3.5 "	18.02
1904	Pasture	101.2 ds	3.62	Corn	46.1 bu	13.78	Pasture	95 days	3.39
	10 years Average		12.96	9 years Average		14.11	8 years Average		13.82
	5 years Average		9.90	5 years Average		14.07	4 years Average		13.06

TABLE XLIX—(Continued).

	PLOT 8			PLOT 9			PLOT 10		
	Rotation: Barley; Pasture; Pasture; Pasture; Corn.			Rotation: Wheat: Timothy & Clover Meadow; Timothy & Clover Meadow; Oats; Corn			Rotation: Wheat; Timothy and Clover Meadow; Timothy and Clover Meadow.		
Year	Crop	Yield	Value	Crop	Yield	Value	Crop	Yield	Value
1895	Barley	37.8 bu	$12.51	Wheat	23.1 bu	$14.74	Wheat	24.7 bu	$15.76
1896	"	35.0 "	11.58	Tim. Clo	1.77 T	9 12	Tim. Clo	2 47 T	12.72
1897	Pasture	1.87 T	9.63	" "	2.37 "	12 21	" "	2 9 "	14.94
1898	"	2.0 "	10.30	Oats	60.1 bu	13.94	Wheat	22 0 bu	14 04
1899	Corn	52.7 bu	15.76	Corn	43 0 "	12.86	Corn	43 0 "	12.86
1900	Barley	20.6 "	6 82	Wheat	20.1 "	12.82	Wheat	21 0 "	13 40
1901	Pasture	221 days	7 89	Tim Clo.	1.6 T	8 24	Tim Clo	2 1 T	10 82
1902	Meadow	1.4 T	7.21	" "	1 75 "	9 01	" "	1 7 "	8.76
1903	"	6.2 "	31.93	Oats	54 0 bu	12 53	Wheat	22.5 bu	14.36
1904	Pasture	319.8das	11.42	Corn	34 4 "	10 29	Meadow	4 77 T	24.57
10 year Average,			12.41			11.58			14.22
5 year Average,			13.01			10.58			14.38

SERIES IV.

Table XLIX gives in the upper left hand corner the average yield and cash values of the crops produced on the three check plots of this series. The average cash value of the crops for ten years is $13.79. This furnishes a fair basis for comparison of the rotations on the other plots of this series.

Plot 2. Plot 2 has made a very good record as compared with plot 1, or compared with an average of the three check plots in this series. The average, however, is based on the average for nine years, but since the crop of 1899 was plowed under for green manure, and as that is the plan of the rotation, the total for the nine years ($117.55) should readily be divided by ten, giving an average annual crop value of $11.76. It is practical in but very few instances in Minnesota to follow the practice of green manuring. If it is decided to let a piece of land lie idle for one year for such purpose, it is very much better where clover can be grown, to sow clover, the year before with the grain crop and plow under either the first or second crop of clover. As a rule, it does not pay to plow under either crop of clover if there is any prospect of being able to feed the clover to advantage on the farm. The manure resulting from feeding or pasturing such crops, especially if some grain is fed at the same time, is worth nearly as much to the soil as the green crop plowed under. Crops used in this way furnish roughage very cheaply.

THE FLAX CROP.

Plot 3. The idea that flax is a hard crop on the soil is probably a mistaken one, as shown by results on plot 3. It will be seen that this plot has given results a little better than the average of the three check plots, and but a few cents below the yearly average of plot 1, the nearest check plot.

TABLE L.—Fertility Removed by Wheat and Flax (a).

	Nitrogen. Lbs.	Phosphoric Acid. Lbs.	Potash. Lbs.
20 bu. of Wheat and Straw	35	20	35
15 bu. of Flax and Straw	54	18	27

(a) From Snyder's Chemistry of Soils and Fertilizers.

The above table shows that flax removes less phosphoric acid and potash than does wheat, but considerably more nitrogen. Nitrogen is a very necessary element of plant food, but since it is cheaply returned to the soil by the growing of clover or other legumes, the fact that a little more is removed by one crop than by another is not so important.

FLAX WILT.

One reason why flax is supposed to be hard on the soil is on account of the disease "flax wilt" which makes it impossible to grow flax for many years in succession on the same soil.

Flax wilt is a fungus disease that attacks the smaller flax plants. It lives over winter or for several years in the ground, hence when the soil is once affected it remains so for four to six years. In countries where flax is an important crop it is grown on the same field but once in five to ten years. Flax is one of our most profitable grain crops and can very well enter into a rotation on many Minnesota farms. It is not harder on the land than are other grain crops, and, as shown on plot 3, it is often a good nurse crop with which to seed grasses.

TANKAGE.

Plot 9. The only other plot in this series requiring any special mention is Plot 9. By looking over Fig. 12, Page 303, showing the rotation of this plot, it will be observed to be the same as the standard five year rotation except that tankage was applied to the corn instead of barnyard manure. The yields have not been so high on this plot as on the check plots· It was planned to add as much fertility in the tankage as would be added by eight tons of manure. The lower yields may be due to some inequality in the plots, but it is very likely due to lack of humus. The tankage would not increase the humus supply as much as would the manure.

PART II.

INFLUENCE OF ROTATION OF CROPS AND CONTINUOUS CULTIVATION UPON THE COMPOSITION AND FERTILITY OF SOILS.

HARRY SNYDER.

In the spring of 1892 a field that had produced small grains for about forty years was divided into six plots, and each plot was subjected to a different system of cropping. At that time and subsequently at intervals of four years samples of soil were taken from each plot and analyzed to determine the extent to which changes had occurred in the soil due to the different systems followed. The soil was quite uniform in composition and was well suited to a study of the income and outgo of fertility. In bulletins Nos. 53, 70 and 89 of this station are reported the changes in the physical properties of the soils, the losses of nitrogen and humus when grains were grown continuously and the gains when they were rotated with clover.

The experiments undertaken in 1894 were joint investigations of the divisions of Agriculture and Agricultural Chemistry. The preliminary plan of the field project is given in the Minnesota Experiment Station Report of 1893 by William M. Liggett, at that time Chairman of the Agricultural Committee of the Board of Regents and Chairman of the Station Council. A more extended discussion may be found in Bulletin No. 40. The various rotations were planned and inaugurated by Professor Willet M. Hays, while Agriculturist of the Station. The part taken by the Division of Agricultural Chemistry has been confined to a study of the income and outgo of the fertility of the plots as influenced by the different systems of cropping. The Division of Agriculture has concerned itself with the yield and income from the different rotations, and the various problems relating to farm management.

At the close of the ten year experimental period, a large amount of analytical work in connection with these fertility studies was involved; fortunately at about this time Congress passed the Adams Act, providing funds for research work in scientific agriculture, and these investigations were made a feature under this act. Otherwise the analytical work would have progressed more slowly for lack of funds. Later the soil investigations were placed upon a more permanent basis by the University Regents establishing the Division of Soils. A small portion of the special appropriation made by the State Legislature of 1906 for Soil Investigations has also been used in connection with this work.

An extended statement of the rotations proposed and the location of the plots is given by Professor Hays in Bulletin No. 40, from which the following is quoted:

"ROTATION OF CROPS.

"The Divisions of Agriculture and Agricultural Chemistry have undertaken the joint study of the rotation of crops.

"In the spring of 1894, forty-four plots, each two by eight rods, one-tenth acre, were laid off on fairly uniform land on the northeast corner of the university farm. The land is a medium heavy clay loam or slightly modified till soil of good fertility, naturally well underdrained and able to retain a large amount of capillary moisture through periods of severe drought. The plots are in four series running east and west and containing eleven plots each, these running north and south. Between each series the ends of the plots are separated by alleys a rod wide, and between each pair of plots are alleys twelve feet wide, an alley two feet wide separating the two plots of the pair. This separates the plots and enables the teamster to reach all plots in using any machine without unnecessary tramping."

Former Results and Conclusions.

The earlier conclusions reached in studying the influence of continuous cropping and the rotation of crops upon soil fertility have been verified in the more extended series of experiments reported in this bulletin. The results obtained some fifteen years ago in a study of the fertility of native and long cultivated soils, and published in Bulletin No. 30, 1893, apply equally well to this investigation. With slight modifications and some additions, the former conclusions could consistently be repeated as those reached in the experiments reported in this bulletin. The former conclusions, Minnesota Bulletin No. 30, 1893, are as follows:

"1. Continued cropping of soils to grains only, without any system of rotation, or other treatment, is telling severely upon the original stock of half decomposed animal and vegetable matter and nitrogen. Soils which have produced grain crops, exclusively for ten or fifteen years, contain less humus and nitrogen than adjoining soils that have never been plowed.

"2. Soils which have been cropped until the organic matter and humus have been materially decreased, retain less water and dry out more readily than when there is a larger amount of organic matter present in the soil.

"3. Soils which are rich in humus contain a larger amount of phosphates associated with them in available forms than soils that are poor in humus.

"4. Soils which are rich in humus and organic matter produce a larger amount of carbon dioxide, which acts as a solvent upon the soil particles and aids the roots in procuring food.

"5. One-half of a sandy knoll, heavily manured with well rotted manure, contained nearly a quarter more water during a six weeks drought, than the other half that received no manure.

"6. The supply of organic matter in the soil must be maintained because it takes such an important part, indirectly, in keeping up the fertility. A good system of rotation, including sod crops and well prepared farm manures, will do this, and will avoid the introduction and use of commercial fertilizers which are now costing the farmers of the United States over thirty-five million dollars (now eighty million) annually. It will not do to wait until this question forces itself upon us.

"7. A rotation of crops will soon be necessary on account of the peculiar composition of some of the soils and corresponding subsoils, especially those where the surface soils are richer in phosphates and nitrogen while the subsoils are richer in potash and lime. By means of rotation the full benefit of the strong points of both the top soil and the subsoil will be secured."

The decay of the humus and liberation of its nitrogen is only one of many changes that has taken place. Loss of the element nitrogen cannot be said to be the only cause of decline in fertility, as field experiments with fertilizers on old grain lands show that nitrogen alone, when added to the soil, fails to entirely restore the fertility. In addition to the decay of the humus and loss of nitrogen, the mineral elements of plant food have undergone changes in combination, the soils have become lighter in color and otherwise modified in physical properties.

To restore the fertility of the soil two methods of procedure are open: Keeping live stock with production and use of manure, or use of commercial fertilizers. The best results will probably be secured by a judicious combination of the two methods. To produce on all farms enough manure to maintain the fertility of the soil would require the keeping of a large number of live stock, and this would eventually result in over production. There are large areas of soils, originally of high fertility, where the rotation of crops, moderate use of farm manure ultimately supplemented with commercial manures will give the best financial results.

The conclusions reached in regard to the use of commercial fertilizers are given in Bulletins Nos. 94 and 102 of this Station, from which the following quotations are taken:

"Commercial fertilizers should not be used indiscriminately on old soils with a view of securing large yields, and it is not feasible by their use 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 employed in a rotation 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 applying them in large amounts it is recommended that farmers 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 aid in the production of some crops and often assist a crop, as clover, which in turn is beneficial in adding nitrogen and humus to the soil.

"Commercial fertilizers should be used in connection with crop rotations, farm manures and clover production, rather than as the only means of increasing the fertility. When judiciously used, they have a proper place in our agriculture, but when indiscriminately applied it is generally at a financial loss."

In addition to this study of the losses of nitrogen and humus at the University Farm, similar investigations were made on a number of farms of students of the Minnesota School of Agriculture. From definitely located points in large fields samples were taken and analyzed, and after the lapse of ten years the same soils were again sampled and analyzed; the results are briefly summarized as follows:

A rotation of grain crops alone, without the production of clover or a grass crop, was found not to be sufficient to conserve the nitrogen content of the soil, even where farm manures were used. A rotation of crops, in order to be effectual, must contain clover as one of the essential parts, as a rotation of grain crops alone, without clover, may deplete the soil nitrogen more rapidly than

TABLE LI.

	Location of Soil	System of Cropping	Nitrogen Content Percent. 1895	Nitrogen Content Percent. 1905	Estimated Loss of Nitrogen Pounds per Acre
1	Red River Valley	Grain	.601	.523	2,000
2	Central Western part of state	A rotation of grain crops, no grass grown, manured once.	.422	.389	1,000
3	Central part of state	Similar to Farm No. 2.	.286	.247	1,200
4	Chippewa River Valley	Similar to Farm No. 2.	.363	.24	3,000
5	Central Southern part of state	Rotation of crops, clover, and farm manure used.	.31	.309	....

continuous cultivation of one crop. It is to be noted that the losses of nitrogen from the large grain farms were practically the same as from the experimental plots at the University Farm.

The beneficial action of a clover sod, grass crop residues, and farm manures upon the soil is not alone confined to supplying nitrogen and humus-forming materials, but chemical, bacteriological and physical changes are also promoted in the soil. The studies made at this station and published in former bulletins show that chemical combination may take place between the decaying, organic compounds incorporated with the soil and the minerals. As a result of this change, plant food is made available. During the decay of animal and vegetable materials, acid products are formed which unite with the minerals of the soil, particularly with the potash and phosphoric acid forming compounds known as humates, which are valuable forms of plant food. In the absence of sufficient alkaline matter in the soil, the acid remains unneutralized and the soil unproductive, but by the addition of lime, wood ashes and other alkalies, this free acid is neutralized and the process of humus production allowed to continue. Hence it is that farm manures and grass crop residues are valuable, not only for the fertility which they contain but also bcause of their favorable action upon the inert mineral matter of the soil, rendering it available as plant food. Experiments at this station have shown that the mineral matter combined with the humus may serve as plant food. Oats and wheat have been grown in which all of the mineral plant food was derived from that combined with the humus.

The indiscriminate practice of bare summer fallowing has been another cause of loss of the soil's nitrogen and humus. The occasional fallowing of land to destroy insect pests and weed seed is often necessary, but the alternation of grain and summer fallowing is particularly destructive to the humus by encouraging rapid decay with liberation of the nitrogen. Fallowing is temporarily beneficial, a few good crops being secured, but it is at the expense of permanent fertility. Experiments show that when summer fallowing is practiced five times more nitrogen is rendered soluble and available than is required for the succeeding crop; and the soluble nitrogen that is not utilized as plant food is readily lost. There is no soil so rich in nitrogen that it can endure the long continued practice of summer fallowing without ultimate decline in fertility.

Particular stress is laid upon the nitrogen and humus of the soil because they may be controlled by cultivation, and if the humus and nitrogen content is maintained the problem of fertility is greatly simplified. The maintenance of the mineral plant food of the soil cannot be neglected, but the mineral matter is not subject to such large gains and losses as the nitrogen.

On most western farms it is more economical at the present time to make the reserve mineral matter available as plant food than to purchase new stores. In many soils there is a large amount which is not in the most available forms, but is capable of being made so by cultivation. It should be the aim to keep this reserve fertility in such a condition that it will gradually become available and can be drawn upon by future crops. When the soil is made to produce one crop year after year, there is but little opportunity for the reserve fertility to become available.

The mineral elements of plant food, it should be remembered, are present in and form a part of the microscopic soil particles. The plant obtains its food from these particles, and the less decomposed they are, the more difficult it is for the plant to utilize them. If proper means are taken, it is possible to have some mineral food in all the different stages of decomposition, so that as soon as the most available is taken up by the crop there are other forms ready to be acted upon and made available to take the place of that which has been removed. Chemical and physical changes are continually taking place in the soil, and in some soils these changes are more rapid than in others. In the cultivation of the soil it should be the aim to assist nature in bringing about those changes which render the plant food available.

While a rotation of crops in which clover forms an essential part may result in maintaining the nitrogen and humus content, there is, after a series of years, a material loss of mineral plant food, as potash and phosphate compounds. In fact, a rotation of crops removes more total mineral plant food from the soil than when a grain crop is grown continuously, and thus a rotation may hasten the exhaustion of fertility. A rotation of crops, with the occasional use of farm manures and the production of clover, will not indefinitely maintain the fertility of all soils; only those soils that are naturally fertile and contain large amounts of reserve plant food will indefinitely respond to such a system of cropping.

On some soils the rotation of crops only hastens exhaustion of the fertility by causing a larger total amount of plant food to be removed, and where large reserves do not exist in the soil the use of commercial fertilizers will be necessary. At the present time and in the case of prairie soils that are beginning to show the effects of excessive grain production, rotation of crops and the production of clover will be more beneficial than any other means for restoring fertility. This will assist in securing larger yields for a series of years, but will not prove the final solution of the problem of maintaining the fertility of the soil.

In connection with the rotation experiments, tests have been made to determine the draft of farm crops upon the soil as to the amount of nitrogen, phosphoric acid and potash required by the plants as food. These results are published in Bulletins Nos. 29, 34 and 47. It has been found that farm crops do not remove large amounts compared with the total mineral matter in the soil, but only very small portions of the mineral elements are available as plant food at any one time. Crops make their draft upon the soil mainly in the early stages of growth, as the mineral food is required in advance of the formation of plant tissue. Growth is often checked for lack of a good supply of available plant food at the time crops are passing through their first or formative stage. A plant, like an animal, if starved while young can never regain its normal growth by later liberal feeding.

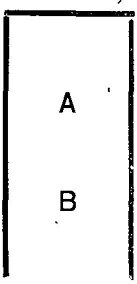
In these investigations much attention has been given to the physical condition of the soil as modified by the rotation of crops. Briefly stated, it has been found on the plots where the rotations were followed that the soils when wet are somewhat darker in color than where grain or root crops were grown continuously. The loss of humus has slightly affected the weight of the soil per cubic foot, and the apparent specific gravity, the loss not having been sufficient, however, to materially affect the absolute specific gravity. Laboratory tests show that the soils from the rotated plots respond more favorably to heat and water than the soils from the continuously cropped plots. The rotated soil plots absorb about 5 per cent more water and do not cake so badly or form as hard lumps when dry as the soils from the continuously cultivated plots. Also tests as to moisture content during periods of drought showed larger amounts of water in the rotated plots. The humus made the soils more mellow and restored that condition commonly called "good tilth."

Thorough cultivation of the soil is the first essential for the successful production of crops, and frequently this is neglected by the cultivator. Without the right kind of cultivation good seed and fertilizers will accomplish but little in the way of larger crop yields. The yields from the plots where wheat and other grains were grown continuously and in rotation were in part secured through the thorough cultivation, but cultivation alone, valuable and important as it is, will not solve the problem of better crops. Cultivation must be combined with a judicious system of manuring. During the first decade of these rotation experiments the reserve fertility of the soil has been drawn upon for maintaining crop yields, during succeeding periods the reserve fertility will become less active, and undoubtedly it will be necessary to re-enforce it with one or more of the elements of plant food, as potash or phosphates. Cultivation cannot take the place of manures, neither can manures take the place of cultivation. Both are important in crop production. It is undoubtedly the sum of all these factors, physical, chemical and bacteriological, that enables larger yields of crops to be secured from the rotated plots. It cannot be said to be due to physical conditions alone, because it is impossible to improve the physical condition of the soil without at the same time bringing about a series of chemical and bacteriological changes. There is such an intimate relation between the physical, chemical and bacteriological changes in the soil that it is impossible to cause one to take place without also influencing or inducing the others. A rational explanation of crop rotation must be founded upon physical, chemical and bacteriological grounds.

In this bulletin, special emphasis has been laid on maintaining the humus supply of the soil, because the humus acts on the soil in all of the three different ways mentioned, physical, chemical and bacteriological, and brings about desirable changes, but, as previously stated, maintaining the humus does not alone permanently solve the problem of soil fertility in connection with crop production.

Methods of Analysis.

Sampling Soils. The method of the Association of Official Agricultural Chemists was followed in sampling the soils, and the samples were taken from definitely located points.



In each plot two points, A and B are located. A is situated one rod from the east and two rods from the south boundary line, while B is one rod from the east and two rods from the north boundary line. From A as a center ,and within a radius of five feet, three samples of soil were taken to a depth of six inches. In the same way three samples were taken with B as the center. These samples were mixed to form a composite sample. At both the beginning and the close of the experimental period the soils were sampled in the same way. It is believed that by taking the samples from definitely located points the difficulties in the way of securing comparable samples are reduced to a minimum. It is to be noted that in these experiments the surface soils were sampled to a depth of *six* inches while in the experiments reported in earlier bulletins the soils were sampled to a depth of nine inches. It was found that, if the samples were taken to a depth of *nine* inches, a little of the subsoil would be included in the case of some of the forty-four plots. The plots were fairly uniform, but not as uniform as those used in the earlier trials. While the rotation experiments on the forty-four plots were started in the spring of 1894, the soils were not sampled until the following year.

Nitrogen. The nitrogen was determined by the Kjeldahl method, about twenty grams of soil being used for the purpose. The method for determination of nitrogen is recognized as one of the most accurate determinations in analytical chemistry. Samples of the soils collected and analyzed in 1895 were dried and stored in glass cans. When the 1905 samples were analyzed some of these former samples were re-analyzed with the view of checking any minor errors arising from the work being done at different times and under possibly different conditions. In all cases a reasonably close agreement of results was secured.

The nitrogen results plainly indicate that the errors arising from sampling and in the analytical work are comparatively small, and that the variations in the nitrogen content of the soils at the beginning and at the close of the experimental period are due to actual changes which have taken place in the soils and not to uncontrolable errors. In a former bulletin, No. 70, page 254, it is stated: "Since nitrogen is of so much importance in plant growth, it is essential it should be accurately determined, and while the percentage amount of the nitrogen in a soil is comparatively small, methods have been devised for determining this small amount with a high degree of accuracy. The results are given as percentage amounts; .222 per cent of nitrogen means that in 100 pounds of dry soil there are .222 pounds of nitrogen. Duplicate determinations of the same soil when carefully made, agree to within .004 of a per cent and less. Hence any material increase or decrease of nitrogen, as .01 of a per cent or more as shown by analysis is due to a loss or gain of nitrogen from the soil caused by the method of cultivation."

In order to secure data as to the influence of slight variations in the depth of sampling upon the nitrogen content of the soils, samples were taken from one of the plots to various depths, as follows:

Soil Inches	Nitrogen Per cent.
1 to 6	.242
1 to 7	.237
1 to 8	.217

The decrease in the nitrogen content of the samples of soil was nearly proportional to the increase in the depth of sampling. A change of one inch in the volume of the first seven inches affected the nitrogen results to the extent of .005 per cent. Since the soils of these experiments were sampled under similar conditions at the beginning and the close of the experiment, it is believed that any error introduced through change of volume of soil would amount to less than an inch in depth, or .005 of a per cent.

In nitrogen determination of food materials results to the third decimal place are not reported ,as they are not generally considered by chemists to be reliable. In the case of soils, however, the results to the third place bear the same relation, as far as accuracy is concerned, as the results to the second place in the analysis of foods. An analyst is not considered as possessing a high degree of skill if he is unable to duplicate his results to within .05 of a per cent for a material containing one per cent of nitrogen. In the determination of nitrogen in foods, from .7 to 1 gram of the material is usually taken, and in the case of soils containing .2 to .3 per cent of nitrogen, from 10 to 20 grams. When the substance, as soil, contains a small per cent of nitrogen, and a large amount of the substance is used for the determination, the accuracy of the results expressed by the third decimal is proportionally increased. Lawes and Gilbert, in their extensive investigations on soil nitrogen, often report their results to the fourth decimal place, and Warington gives all of his soil nitrogen results to the third decimal place. When the soil samples are accurately and systematically taken and the analytical work is carefully done, it is believed it is safe to attribute any difference in nitrogen content of .01 of a per cent to change in nitrogen content of the soil brought about by the methods of cultivation.

Humus. No direct determinations were made of the humus content of the soils at the beginning and close of the experimental period, because the present methods for its determination are not sufficiently accurate to warrant comparisons being made where the changes in humus content amount to less than one per cent. The change in organic content of the soils was, however, determined from the gains and losses of the element carbon, which is a constituent that makes up over 50 per cent of humus. The determination of total organic carbon by combustion analysis, like the determination of nitrogen, is accurate.

When the carbon and nitrogen results are jointly considered, they show not only the amount but also the general nature of the changes which have taken place in the organic matter (humus) of the soil due to the different systems of cultivation.

The humus and organic compounds exert a modifying influence, both physically and chemically, upon the composition of the soil. Briefly stated: humus yields through processes of decay nitrogen as food for plants; it combines with the inactive mineral matter of the soil to produce humates, which are valuable forms of plant food, and when humus is incorporated in soils, there is improvement in the general physical properties or tilth. To secure the highest benefits from humus, the soil should contain a slight amount of active alkaline material which readily combines with the organic acids produced from the decay of the humus and forms humates. Excessive decay of the humus takes place in new soils that are cropped exclusively to small grains. A moderate decay of the humus is desirable, so as to render the nitrogen and mineral matter available as plant food. As previously stated, one of the chief benefits derived from rotating crops is the maintenance of a liberal supply of nitrogenous humus in the soil.

Potash and Phosphoric Acid. No attempt was made to study the total losses of phosphorus and potassium from the various plots. The soils are characterized by a high percentage of phosphorus compounds, about .20 of a per cent of phosphoric anhydrid, P_2O_5 Small crystals of apatite or phosphate rock are occasionally observed in the mechanical analysis of these soils. As the surface soils contained 4,000 pounds per acre of phosphoric anhydrid and approximately 250 pounds were removed in the ten crops, it is quite evident that the determination of the total phosphoric acid would fail to show any decline, as the amount lost would be less than the limit of error involved in its determination. In the case of the nitrogen, the losses are much greater, as it is both utilized as plant food and lost when excessive decay of the humus occurs.

the nitrogen being rendered both soluble and volatile. The changes in solubility of both the phosphorus and the potassium compounds during the ten years of different methods of cultivation were determined. The method followed, the fifth normal nitric acid, is described in the Methods of Analysis of the Association of Official Agricultural Chemists. Slight changes in the solubility of the potash compounds appear to have taken place during the ten year period, but no appreciable change in the solubility of the phosphoric acid in the dilute nitric acid seems to have occurred.

To show the general chemical composition, an analysis was made of the soil of one of the plots of each of the four series. The average of the four analyses is as follows:

TABLE LII.—Chemical Composition of Soil.

	Per cent.
Total Insoluble Matter	82.51
Potash (K_2O)	.28
Soda (Na_2O)	.18
Lime (CaO)	.57
Magnesia (MgO)	.28
Iron (Fe_2O_3)	.2.79
Aluminia (Al_2O_3)	5.16
Phosphoric Anhydrid (P_2O_5)	.21
Total Volatile Matter	7.82
Total	99.80

In Tables Nos. 53, 54, 55, 56, are given the percentage amounts of nitrogen and carbon in the dry surface soils, and the phosphoric anhydrid and potassium oxide soluble in fifth normal nitric acid for the forty-four plots, at the beginning and at the close of the experimental period. The tables also give the systems of rotation followed. Credit is due Messrs. J. A. Hummel, A. D. Wilhoit and W. H. Frazier for valuable assistance rendered in the analytical work. The following tables give the composition of the soils from the forty-four rotation plots, sampled in 1895, and again in 1905 after ten years of cropping. The rotations, as originally proposed, are in the first column. In a few cases it has been necessary to slightly modify the original plans because of failure to secure a grass crop at the place desired in the rotation. These changes are indicated by foot notes. The results are all on the basis of dry soil, and include total nitrogen, total carbon, phosphoric acid, and potash soluble in fifth normal nitric acid.

TABLE LIII.—Soil from Plots, Series No. 1.

	COMPOSITION IN 1895				COMPOSITION IN 1905			
	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid
Plot No. 1. Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr	.229	3.00	39.54	195.0	.234	3.04	38.63	138.0
1. Plot No. 2. Rotation: Wheat, 1 yr.; bromus, 1 yr.; oats, 2 yr.; corn, 1 yr.	.231	3.06	51.76	195.2	.202	3.12	89.77	199.2
Plot No. 3. Rotation: Wheat, 1 yr.; timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr.	.234	2.85	53.69	232.4	.217	2.92	41.61	156.7
2. Plot No. 4. Rotation: Wheat, 1 yr.; clover and timothy, 1 yr.; oats, 1 yr.; corn, 1 yr.	.218	2.90	19.16	....	.239	3.09	49.48	176.5
Plot No. 5. Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; millet, 1 yr.	.222	....	58.65	292.7	.247	....	68.45	156.2
Plot No. 6. Rotation: Wheat 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr., corn, 1 yr.	.217	....	57.58	....	.231	....	60.04	163.3
Plot No. 7. Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; mangles, 1 yr.	201	......	54 58	275.0	.204	....	51.27	177 7
Plot No 8 Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr; rape, 1 yr.	201	....	75.11	165 6	206	....	46 26	149 8
Plot No 9. Rotation: Wheat, 1 yr; clover and timothy, 2 yrs.; oats, 1 yr., potatoes, 1 yr	209	....	76 26	149 7	.217	....	79 65	174 6
Plot No 10 Rotation: Wheat, 1 yr; clover and timothy, 2 yrs; oats, 1 yr.; sunflower, 1 yr.	198	2 72	74 63	155.5	.203	2.72	84.90	193 8
Plot No. 11. Rotation: Wheat, 1 yr; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 2 yrs.	.226	3.10	123 18	197.5	.226	2.99	117.00	126.0

1 In 1897 oats, and 1902 bromus.
2 Wheat in 1901 and clover 1904.

TABLE LIV.—Soils from Plots, Series No. 2.

	COMPOSITION IN 1895				COMPOSITION IN 1905			
	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid
Plot No. 1. Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr.	.239	....	111 61	213 3	261	....	112 65	179 3
3. Plot No. 2. Rotation: Corn, 1 yr.; peas, 1 yr.; barley, 1 yr.; clover, 1 yr.	254	2 75	85 92	....	273	2 95	78 98	141 6
Plot No. 3. Rotation: Barley, 1 yr.; oats, 1 yr.; timothy, 2 yrs.	*	2 70	90.49	361 5	*	2 81	71 74	150 9
Plot No. 4. Rotation: Barley 1 yr.; oats, 1 yr.; timothy, 2 yrs.	*	2 58	....	178 7	*	2 73	76 02	149 6
Plot No. 5. Rotation: Millet, 1 yr.; barley, 1 yr.; oats, 1 yr.; corn, 1 yr.	... .	3 02	91.75	248 0	.225	3.02	79 01	101 3
Plot No. 6. Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr.	.214	3 00	53.41	162.5	209	3.10	93 19	147 2
Plot No. 7. Rotation: Corn in hills continuously.	.219	2.94	54.81	172.4	.179	2 40	54 51	115.7
Plot No. 8. Rotation: Potatoes continuously.	.212	2.93	55.35	163.7	.178	2.27	57 24	105.4
Plot No. 9. Rotation: Mangles continuously.	.223	2.95	76.23	142.0	.190	2.50	73 72	....
Plot No. 10. Rotation: Peas, field, in drills continuously	....	... .	110.03	....	....	....	75 99	128 2
Plot No. 11. Rotation: Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr.	.210	2.97	....	....	.219	3.05	311.00	173 8

* Plots in slight depression, results excluded.
3. Peas in 1898 and 1899, and corn in 1897.

TABLE LV.—Soil from Plots, Series No. 3.

	COMPOSITION IN 1895				COMPOSITION IN 1905			
	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/6 nitric acid	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid
Plot No. 1. Rotation: Wheat, 1 yr; clover and timothy, 2 yrs; oats, 1 yr; corn, 1 yr	.215	....	102 9	170.8	.232	....	98 46	145.4
Plot No. 2. Rotation: Wheat continuously, fall: plow early.	.229	3.03	107.7	....	.201	2 71	102 7	145.4
Plot No. 3. Rotation: Wheat continuously; sow 6 lbs. red clover with wheat.	.223	....	101 0	191 8	.253	....	78 0	141.4
4 Plot No. 4. Rotation: Wheat, 1 yr; clover, 1 yr; plow under second crop.	.215	2.51	79.25	....	.250	3.34	73 97	1[illegible]1.5
4 Plot No. 5. Rotation. Wheat, 1 yr; clover, 1 yr, save second crop clover for seed or hay.	.215	2.93	112.6	165.3	.250	3 24	74 99	177.3
Plot No. 6. Rotation: Wheat, 1 yr; clover and timothy 2 yrs; oats, 1 yr; corn, 1 yr.	.220	3.02	86.20	195.26	.253	3.11	79.12	164.0
5. Plot No. 7. Rotation: Wheat, 1 yr; permanent pasture, red clover, timothy, red top, Kentucky blue grass, orchard grass, bromus, alsike and white clover.	.229	3 09	92.31	....	.233	3.16	56.21	143.6
5 Plot No. 8. Rotation: Wheat, 1 yr; permanent meadow, red clover, alsike clover, timothy, orchard grass, bromus.	.221	2.91	58.37	....	.224	2.97	42.26	131.9
Plot No. 9. Rotation: Millet, 10 yrs, and some clover.	.217	....	121.4	....	.224	....	124.4	1[illegible]
Plot No. 10. Rotation: Rape continuously, drill pasture off.	.211	3.00	81.84	....	....	3.10	76.70	153.4
Plot No. 11. Rotation: Wheat, 1 yr; clover and timothy 2 yrs; oats, 1 yr; corn 1 yr.	.220	....	90.42	140.4	.257	....	89.04	155.5

4. Wheat 1897 to 1900.
5. Wheat 1898.

TABLE LVI.—Soils from Plots, Series No. 4.

	COMPOSITION IN 1895				COMPOSITION IN 1905			
	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid	Total Nitrogen Per cent	Total Carbon Per cent	Phosphoric acid Parts per million Soluble in n/5 nitric acid	Potash Parts per million Soluble in n/5 nitric acid
Plot No. 1. Rotation: Wheat, 1 yr; clover and timothy, 2 yrs; oats, 1 yr, corn, 1 yr	.231	2 96	73 05	187.5	.253	3.32	76.07	175.2
6. Plot No. 2 Rotation: Wheat, 1 yr; clover and timothy, 2 yrs: oats 1 yr, green manure 1 yr; plow under crop of mixed oats early in summer late in fall a crop of rape.	.214	3 04	68.69	151 1	.239	3.45	42.14	150.5
Plot No 3 Rotation: Flax 1 yr; clover and timothy, 2 yrs; oats, 1 yr corn, 1 yr	.236	....	105 4	243 2	.250	....	71.56	149.2
7. Plot No. 4 Rotation: Barley, 1 yr; clover and timothy, 1 yr; pasture, 2 yrs field pea hay, 1 yr.	.201	....	102 5	231 0	.228	....	48.25	132.0
8. Plot No 5. Rotation. Corn, 1 yr. rye and rape, 1 yr, barley, 1 yr, pasture, timothy, red and alsike clover, 3 yrs	.208	....	122 8	170 6	.230	....	123.8	145.6
Plot No. 6. Rotation: Wheat 1 yr; clover and timothy, 2 yrs: oats, 1 yr; corn, 1 yr	.201	2 94	91 76	154 1	.215	3.04	76.58	108.3
9 Plot No 7. Rotation: Corn, 1 yr; rye, 1 yr; pasture, timothy, red and alsike clover, 2 yrs; barley 1 yr; peas, 1 yr.	.208	2 69	78 49	129 8	.218	2 89	72.71	115.3
Plot No. 8. Rotation· Barley, 1 yr; pasture, timothy, red and alsike clover, 2 yrs; corn, 1 yr	.209	....	129.5	146.3	.225	....	75 58	110.8
Plot No 9. Rotation: Wheat, 1 yr; timothy and clover, 2 yrs; oats, 1 yr; (tankage) corn.	.208	2 70	85 42	145 0	212	2 88	100 6	157.2
10. Plot No 10 Rotation: Wheat, 1 yr; timothy and clover, 2 yrs.	.209	2.68	94.19	160 6	.220	2.84	56.28	....
Plot No. 11. Rotation: Wheat, 1 yr; clover and timothy, 2 yrs; oats, 1 yr; corn, 1 yr	.207	....	115.9	155.3	.214	....	96.14	146.8

6. No green manure, but oats in 1904. 7. Corn in 1900. 8. Rye in 1895.
9. Rye in 1895 and oat hay, 1902. 10. Corn, 1899.

Discussion of Results.

Control Rotation Plots. Twelve of the plots, Nos. 1, 6, and 11 of each of the four series, were designated as control plots and on all of these the same rotation was followed; namely: wheat, one year; clover and timothy, two years; oats, one year; corn (fertilized with eight tons of farm manure per acre), one year. The clover and timothy were seeded with the spring wheat, and usually a good stand of clover was secured the first year. The first year of meadow, clover predominated, and the second year timothy. It is to be noted that there was some clover produced during three of the five years. The nitrogen and carbon content of these twelve control plots, at the beginning and close of the ten year period, are given in the following table.

It is to be noted that ten of the twelve plots contained more nitrogen at the close than at the beginning of the experimental period, one contained the same amount, and one showed a slight loss. The average nitrogen content of the twelve plots in 1895 was .219 per cent, and in 1905 .233 per cent, a gain of .014 per cent. The maximum gain of .037 per cent was secured on Plot 11, Series III, while Plot 6, Series II, showed a loss of .005 per cent. Taken as a whole, the results show a slight gain of nitrogen during the ten years. This gain does not include the nitrogen removed as plant food by the crops, amounting to nearly 500 pounds per acre. The average gain of .014 per cent is greater than possible limits of error, and the larger portion of this can be attributed to no other cause than to an actual increase in the nitrogen content of the soils.

The accumulation of nitrogen in soils where clover and other legumes are grown, has been well established by Hellriegel and a number of other investigators. The extent to which soils may gain or lose nitrogen when grains and legumes are grown in rotations has not heretofore been extensively studied.

In these rotations, in which clover was grown during two years of the five, the nitrogen accumulated from at-

TABLE LVII.—Nitrogen and Carbon Content of Control Plots.

Series No.	Plot No.	Nitrogen Per cent 1895	Nitrogen Per cent 1905	Carbon 1895	Per Cent 1905
I	1	.229	.234	3.00	3.04
I	6	.217	.231	....	....
I	11	.226	.226	3.10	2.99
Average		.224	.230	3.05	3.01
II	1*	.239	.261	....	....
II	6	.214	.209	3.00	3.10
II	11	.210	.219	2.97	3.05
Average		.221	.229	2.99	3.07
III	1	.215	.232	....	....
III	6	.220	.253	3.02	3.11
III	11	.220	.257	....	....
Average		.218	.247	....	....
IV	1	.231	.253	....	....
IV	6	.201	.215	2.94	3.04
IV	11	.207	.214	....	....
Average		.213	.227	....	....
General Average		.219	.233	3.00	3.06

*Plot in slight depression.

mospheric sources was sufficient to supply that required as plant food and to increase the store of total nitrogen in the soil to the extent of .014 of a per cent. It can be said that in these rotations the nitrogen content of the soil was fully maintained, and even to a slight extent increased.

The per cent of carbon obtained by combustion analyses also indicates that an equilibrium was maintained, as the percentage amounts at the beginning (3.00) and close (3.06) of the experimental period are practically the same. The use of the farm manure at the rate of eight tons once in five years, and the production of two clover and timothy crops have been sufficient to maintain the humus and organic compounds of the soil. Any increase or decrease would be followed by a corresponding change in the content of the soil's carbon, inasmuch as humus is over fifty per cent carbon. The rotation fully maintained both the nitrogen and humus content of the soil.

At the beginning of the experiments the soils of the control plots contained an average of 178 parts per million of potash soluble in fifth normal nitric acid, and at the close 153 parts. The general tendency of the potassium compounds has been to become less soluble during the period of the rotations. While the loss was small, it was sufficient to show that the disintegration of minerals containing potash was not equal to the demands of the crop and loss through leaching and drainage. The potash soluble in fifth normal nitric acid was removed from the soil more rapidly than it was liberated by disintegration of the more complex potash containing minerals.

There was no material change in the solubility of the phosphate compounds during the experimental period, as measured by fifth normal nitric acid. In the case of five of the plots there were slight gains in solubility and seven of the plots showed losses. The changes in solubility of the phosphoric anhydrid were not sufficiently pronounced to allow definite conclusion being drawn. The phosphorus compounds of these plots do not appear to be as evenly distributed or as uniformly soluble as the potassium compounds. For a comparison of the fertilizer requirements of soils, as determined by field tests, and chemical methods involving the use of fifth normal nitric acid, the reader is referred to Bulletin No. 102 of this Station.

Rotation without Clover.—Where timothy alone was seeded (Plot 3, Series I), the rotation in other respects remaining the same as on the control plots, there was a loss of .017 per cent of nitrogen. This loss is about 10 per cent greater than the estimated amount removed as food by the crops during the experimental period. The substitution of timothy for clover in the rotation resulted, at the end of ten years, in a difference of .031 per cent of nitrogen in favor of the clover. The carbon (humus) content of the soil was not appreciably affected by the substitution of timothy for clover.

Rotation with Clover and without Corn.—When potatoes and mangels were substituted for corn in the five year rotations (Plots 7 and 9, Series I), clover and timothy being grown as in the standard rotations and farm manure used, the nitrogen content of the soil was maintained. Corn, however, appears to conserve the nitrogen to a greater extent than roots, as the gain in the standard rotations with corn was .014 per cent and when roots were substituted .005 per cent.

Peas and Clover in a Rotation.—When both peas and clover were grown in a four course rotation (Plot 2, Series II) with corn and barley, there was a gain of .019 per cent of nitrogen and .2 per cent of carbon. When the rotation was lengthened to include rye, timothy being seeded with the clover and the land pastured (Plot 7, Series IV) the soil gained .01 per cent of nitrogen and .2 per cent of carbon. In a shorter rotation, where the rye was omitted and the land was one year in meadow (timothy and clover) and two years in pasture, corn, barley and pea hay also being grown, the soil gained .027 per cent of nitrogen. Peas and clover in a rotation appear to add the maximum amount of nitrogen to the soil when clover is produced more than one year.

Wheat and Clover in Rotation.—On a number of plots wheat and clover were combined to form rotations. The influence upon the nitrogen content of the soil is noted in the following table:

All of the combinations of wheat and clover show an increase of soil nitrogen, the gains in general being greater than in the standard five year rotations in which wheat and clover were grown with other crops. Clover, when used as green manure, has a marked effect in increasing the nitrogen content of the soil.

TABLE LVIII.—Nitrogen Content of Soils from Rotation Plots.

	1895	1905
Plot 3 Series III, wheat continuously clover being sown each year with wheat as green manure	.223	.253
*Plot 4, Series III, wheat one year clover 1 year. plow under second crop.	.215	.250
*Plot 5, Series III, wheat 1 year, clover 1 year, second crop used for seed.	.215	.250
†Plot 10, Series IV, wheat 1 year, clover and timothy 2 years	.209	.220

* Wheat 1897 to 1900.
† Corn 1899.

Clover and Flax in Rotation.—Flax was substituted for wheat in one of the five-year rotations (Plot 3, Series IV). Clover and timothy were seeded with the flax; the land was left in meadow for two years and then oats were raised, followed by corn, manured at the rate of 8 tons of stable manure per acre. The substitution of the flax for the spring wheat had no effect upon the nitrogen content of the soil. The gain on the control plots with clover and wheat was .014 per cent nitrogen, and when flax was substituted for the wheat, the gain was also .014 per cent.

In 1896 a study was made of the draft of flax upon the land, and it was found that the fertility removed in a crop of flax yielding 15 bushels per acre was no greater than that removed by many other farm crops. An acre of corn removes more fertility than an acre of flax. The conclusion was reached that "Flax does not remove an excessive amount of fertility from the soil," and it was recommended that it should be grown in a rotation with clover and corn, and farm manure applied to the corn, when good crops of flax would be secured and the fertility of the soil would not be exhausted to any greater extent than if a grain crop were grown. (See Minn. Ex. Station Bulletin No. 47.) In this experiment it is to be noted that when such a system was followed the nitrogen content of the soil was maintained. Intelligent flax growing, in which flax forms one of the crops in a rotation, does not exhaust the fertility of the soil; it is when an attempt is made to grow flax too frequently on the same soil, or on soils that are not properly prepared or adapted to its production, that poor yields result.

Green Manure.—On one of the rotation plots (No. 2, Series IV) a green manurial crop was substituted once during the ten years for the corn of the control rotation. This resulted in increasing the nitrogen content; the total gain during the ten years was .025 per cent, while the gain of the control plots was .014 per cent.

Permanent Pasture and Meadow.—A permanent meadow was seeded on Plot 8, Series III, and a permanent pasture on Plot 7, Series III. Difficulty was experienced in getting and keeping these plots in meadow and pasture. The soils practically maintained a nitrogen equilibrium without any material gain. Clover was seeded on both of these plots, but the non-legumes largely replaced the clover after the second year. It has been necessary to plow up and re-seed both plots.

Miscellaneous Rotation with Clover.—Clover was also grown on a number of plots in rotation with various miscellaneous crops. In all cases the soils increased in nitrogen content, as will be observed from the following table:

TABLE LIX.—Nitrogen Content of Soils from Miscellaneous Rotation Plots with Clover.

	1895	1905
Plot 5, Series IV, corn 1 year, rape and rye 1 year, barley 1 year, clover and timothy pasture 3 years, (rye 1895).	.208	.230
Plot 9, Series IV, wheat 1 year, clover and timothy 2 years, oats 1 year, corn 1 year, (tankage applied).	.208	.212
Plot 8, Series IV, barley 1 year, clover and timothy pasture 2 years, corn 1 year, (stable manure).	.209	.225
Plot 5, Series I, wheat 1 year, clover and timothy 2 years, oats 1 year, millet 1 year, (stable manure).	.222	.247
Plot 10, Series I, wheat 1 year, clover and timothy 2 years, oats 1 year, sunflower 1 year, (stable manure).	.198	.203
Plot 8, Series I, wheat 1 year, clover and timothy 2 years, rape 1 year, (stable manure).	.201	.206
Plot 9, Series III, millet hay 1 year, clover 1 year.	.217	.224

When clover was grown in a six course rotation (Plot 5, Series IV) there was a gain of .022 per cent of nitrogen. When tankage was substituted for the stable manure of the standard rotation (Plot 9, Series IV) the soil nitrogen was not so well conserved as when farm manure was used. On Plots 5, 8 and 10, Series I, millet, rape and sunflowers were substituted for corn in the five course clover rotation, and a gain in nitrogen was secured in each case. There appears to be no large gain in nitrogen content from holding the land more than two years in meadow or pasture. The second year clover gives way to timothy and then the nitrogen previously accumulated may be drawn upon as plant food. On Plot 8, Series IV, barley and corn were grown and the land pastured two years; the gain of nitrogen to the soil was .016 per cent.

Continuous Cropping.—On four plots (No. 2, Series III, and Nos. 7, 8 and 9, Series II), wheat, corn, potatoes and mangels were grown continuously. The soils of all these plots lost nitrogen, as will be observed from the following table:

TABLE LX.—Nitrogen Content of Soils.

Series No.	Plot No.	Rotation	1895 Per Cent	1905 Per Cent	Loss Per Cent
III	2	Wheat, continuously	.229	.201	.028
II	7	Corn, "	.219	.179	.040
II	8	Potatoes, "	.212	.178	.034
II	9	Mangles, "	.223	.190	.033
	Average,		.221	.187	.034

When wheat was grown continuously for ten years, there was a loss of .028 per cent of nitrogen from the soil, and in the case of corn the loss was .04 per cent. The average loss when the grain and roots were grown was .034 per cent. In these continuously cultivated plots no humus forming materials were added, and there was a reduction in the carbon content of over .5 of a per cent, equivalent to about 16 per cent of the total original carbon content of the soil. During the ten years of cultivation, there has been a loss of about 16 per cent of both humus and nitrogen, and this was not confined to the surface six inches alone, less but appreciable loss having taken place from the subsoil.

It is estimated that an acre of the soil of these plots to a depth of six inches weighs in round numbers 2,100,-000 pounds. The loss of nitrogen from the surface soil amounts to 714 pounds and from the subsoil to about 400, making a total loss of 1,100 pounds. It is estimated that about one-third of this nitrogen has been utilized as plant food, and about two-thirds have been lost.

The rapid decay of the vegetable matter (humus) of the soil has resulted in the liberation of more nitrogen than was utilized as plant food. During six or seven months of the year the process of nitrification—change of the humus nitrogen to soluble and available forms—goes on rapidly, and for about half of this time no crop occupies the land to absorb the nitrogen liberated by oxidation of the humus, and consequently a large portion of the available nitrogen, as nitrates formed as the result of nitrification, is lost in the drain waters, or volatile compounds of nitrogen are formed and liberated as gases. It is not possible to retain any large amount of nitrogen in the soil, except in the form of humus.

The factors which assist in rapid nitrification are: presence of lime and alkaline matter, and aeration of the soil such as is secured through continuous cultivation of one crop. The favorable mechanical condition of the soils of the continuously rotated plots, together with the requisite amount of lime, has been the main cause of the rapid nitrification of the humus, and the formation of nitrates through the workings of organisms. When wheat, corn, potatoes and mangels were grown in rotation with clover, new stores of nitrogen, derived from atmospheric sources, were added to the soil, and the rapid decay of the humus was checked. Continuous cropping is a destructive process, and the rotation of crops and the application of farm manures are constructive processes in humus building.

That the larger portion of the loss of nitrogen has been due to rapid nitrification is shown by investigations of Lawes and Gilbert, who studied the rate of nitrification in American soils collected at Winnipeg and other points in the Northwest Territory. These soils they exposed under laboratory conditions for periods of over a year (13 months), and at intervals determined the amounts of nitric nitrogen formed. As they state, these conditions were not strictly comparable with field conditions, but in a general way the results indicate the rapidity with which the nitrification process may take place in prairie soils. The results are given in Vol. VI, Rothamsted Memoirs, Field Experiments, page 417, from which the following condensed statement is made:

TABLE LXI.—**Rapidity of Nitrification of Soils.**

SOIL FROM	Lbs. of Nitrogen per Acre to depth of 1 ft.	Total Lbs. of Nitrogen as Nitric Acid formed		Per Cent of Total
		During period	During first Six Month	
Niverville	7,308	234.1	194.6	3.21
Brandon	5,236	250.4	179.2	4.78
Selkirk	17,304	[illegible]	466.6	3.77
Winnipeg	11,984	650.0	447.2	5.42
Average	10,458	447.4	321.9	4.29

It is to be noted, during a period of six months an average of 321.9 pounds of nitrogen as nitric acid, or nitrate nitrogen, was formed under the conditions of the experiment. At the same rate of nitrification, the amount of nitric nitrogen formed during the spring and summer months for ten years would amount to over 2,500 pounds per acre, or 25 per cent of the total soil nitrogen. This does not include the nitrogen in the form of nitrites and other soluble or volatile forms which are also known to be produced through oxidation of the humus.

When small grains are grown on new land, the loss of nitrogen is undoubtedly greater than when grown on soil that has been under long cultivation. In old soil the humus becomes less active and nitrification does not take place so readily. The rate of nitrification and the amount of nitrogen added to the soils by judicious rotations with legumes can be controlled largely by the farmer. A loss of 1,100 pounds of nitrogen in ten years from soils where wheat, corn, potatoes and mangles were grown continuously, seriously affected the permanent crop producing capacity. Although the soils of these plots still contain a comparatively large amount of nitrogen, this excessive loss caused by continuous cropping was unnecessary and did not occur on the plots where the crops were rotated with clover.

In former investigations, the loss of nitrogen from the soil, to a depth of nine inches, when corn and small grains were grown continuously, ranged from 1,400 to 2,000 pounds per acre in twelve years. Both the former and the present investigations show that continuous cropping to small grains and roots results in depletion of the soil nitrogen, and by far the larger portion is not used as plant food but is lost through rapid decay of the humus and liberation of its nitrogen in volatile and soluble forms.

The losses of organic matter (humus compounds) from the soils have also been large. The analyses show a decline of .5 per cent in the carbon content in ten years. It is estimated that during the ten years the soils upon which the grains and roots have been raised continuously have sustained a loss of over one per cent of organic compounds, equivalent to over 20,000 pounds per acre, or an annual loss of one ton.

Gains of Nitrogen. When wheat was grown in rotation with clover and corn, as in the standard rotation, the average gain of nitrogen to the soil was .014 per cent, equivalent to about 300 pounds in ten years. The maximum gain when clover was grown, .037 per cent on Plot 11, Series III, was equivalent to about 775 pounds, while Plot 6, Series II, showed a loss of .005 per cent, or 100 pounds. With the exception noted, gains are recorded on all of the plots where clover was grown. The gains and losses per acre of nitrogen and carbon are calculated by multiplying the per cent of nitrogen, as obtained by analyses, by the estimated weight per acre of the soil to a depth of six inches. As previously stated, the per cent of nitrogen can be accurately determined, but the weight per acre can only be approximated. In making the calculations, it was deemed best to use the factors representing the maximum apparent specific gravity as determined from the maximum weight per cubic foot of the soil (dry) in situ, and from the computed values obtained from the absolute specific gravity and the apparent specific gravity of the moderately compacted in which the per cent of pore space is known. It is estimated that an acre of the soils of these plots to a depth of six inches weighs under the conditions stated 2,100,000 pounds, in round numbers. Warington states that "nine inches depth of arable soil (clay or loam) will weigh when perfectly dry 3,000,000 to 3,500,000 pounds per acre. King, in the 17th annual report of the Wisconsin Station, page 209, states that three inches depth of stirred soil represents one-fourth of an acre foot, or 100,000,000 pounds, in round numbers.

SUMMARY.

The analyses of the soils of the forty-four experimental plots at the beginning and the close of the ten year period showed:

(1) The maximum amount of nitrogen was lost when the soils were cropped exclusively to wheat, corn, potatoes and mangels. When these crops were grown continuously there was an average loss of .034 per cent of nitrogen, equivalent to 1,100 pounds per acre. In the case of wheat two-thirds of this nitrogen were not utilized as plant food but were lost by the rapid decay of the humus with the formation of soluble and volatile nitrogen compounds. When the crops were grown continuously the soils lost .5 of a per cent of carbon, representing over one per cent of humus, or 20,000 pounds, equivalent to an annual loss of one ton per acre.

(2) There was an average gain of .014 per cent of nitrogen, equivalent to about 300 pounds per acre, in the case of twelve standard rotations, consisting of wheat one year, clover and timothy two years, oats one year, and corn one year, manured with stable manure at the rate of eight tons per acre. From one of the twelve plots there was a small loss of nitrogen. The results, taken as a whole, show the nitrogen content is maintained when clover is grown two years in a five course rotation, and then the

application of nitrogen containing fertilizers is unnecessary. In practically all the rotations where clover was grown, gains of nitrogen were secured. There were no great differences in gains of nitrogen that could be attributed to the combination of any special crops with clover. Any substitution of crops in the rotation could be made without materially affecting the nitrogen content of the soil, provided clover was retained. When the crops were rotated, the carbon and humus content of the soil was maintained and in some cases slightly increased. The results show that wheat, corn, oats, barley, flax, rape, potatoes, mangels, millet, bromus and timothy can be grown with clover in three, four, five or six year rotations without loss from the soil of either nitrogen or humus. By rotations with clover, the nitrogen content was conserved, and in some cases slightly increased. The gains and losses of nitrogen are practically under the control of the cultivator.

(3) In the rotations where timothy and non-legumes were substituted for clover, a loss of nitrogen occurred, but the carbon (and humus) content was maintained. The conservation of the humus prevented rapid nitrification, and the loss of nitrogen from the soil only slightly exceeded that removed by the crops.

(4) The potash compounds of the soil were less soluble at the close than at the beginning of the ten year experimental period. The formation of soluble potash compounds from the decay of the potash minerals did not keep pace with the amount removed as plant food and that lost in soluble forms in the drain waters.

(5) Systems of rotation, in which clover (and other legumes) form an essential part and in which farm manures are used, should be practiced to prevent depletion of the nitrogen and humus of soils, because the humus takes such an important part, chemically, physically and bacteriologically, in maintaing the fertility.

Correction to Bulletin No. 102.

On Plot No. 3, 40 pounds of nitrate of soda, read 32 pounds.

Correction to Bulletin No. 80.

Page 165. In the fifth column, nitrogen free extract, read 39.40, not 38.77. Page 172, Table 77, nitrogen free extract, read 37.48, not 37.03.

Corrections to Bulletin No. 65.

Page 55. Subsoil No. 572, volatile, read 10.30, not 1.30.
Page 56. Subsoil No. 570, add medium sand, 7.43.
Page 56. Subsoil No. 538, silt, read 20.99, not 22.99.

Corrections to Bulletin No. 63.

Page 500. No. 1265, nitrogen free extract, 70.39, not 71.49.
Page 528. Sample 2, total nitrogen .359, not 369.

Corrections to Annual Report.

Page 180c . Sample 1, alfalfa hay, nitrogen free extract, read 37.50, not 34.47, and also sample 8, read 32.30, not 32.09.

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