1930

Aspen : Availability, Properties, and Utilization

R.P.A. Johnson

Joseph Kittredge

Henry Schmitz

UNIVERSITY OF MINNESOTA.

Agricultural Experiment Station.

BULLETIN No. 70.

CHEMICAL DIVISION.

MAY, 1901.

INFLUENCE OF WHEAT FARMING UPON SOIL FERTILITY.

ST. ANTHONY PARK, RAMSEY CO., MINNESOTA.

McGILL-WARNER CO., PRINTERS, ST. PAUL.

UNIVERSITY OF MINNESOTA.

BOARD OF REGENTS:

	Term Expires.
The HON. JOHN S. PILLSBURY, MINNEAPOLIS,	*Regent for Life*
The HON. SAMUEL R. VAN SANT, WINONA,	*Ex-Officio*
The Governor of the State.	
CYRUS NORTHROP, LL. D., MINNEAPOLIS,	*Ex-Officio*
The President of the University.	
The HON. JOHN W. OLSON, ALBERT LEA,	*Ex-Officio*
The State Superintendent of Public Instruction.	
The HON. ELMER E. ADAMS, B. A., FERGUS FALLS,	1902
The HON. THOMAS WILSON, ST. PAUL,	1903
The HON. WILLIAM M. LIGGETT, ST. ANTHONY PARK,	1903
The HON. A. E. RICE, WILLMAR,	1903
The HON. GREENLEAF CLARK, M. A., ST. PAUL,	1904
The HON. T. L. SCHURMEIER, ST. PAUL,	1904
The HON. STEPHEN MAHONEY, B. A., MINNEAPOLIS,	1907
The HON. O. C. STRICKLER, M. D., NEW ULM,	1907
The HON. JAMES T. WYMAN, MINNEAPOLIS,	1907

THE AGRICULTURAL COMMITTEE:

The HON. WILLIAM M. LIGGETT, Chairman.

The HON. JOHN S. PILLSBURY. The HON. J. T. WYMAN.
The HON. ELMER E. ADAMS. The HON. A. E. RICE.

STATION OFFICERS.

WM. M. LIGGETT,	Director.
J. A. VYE,	Secretary.

EXPERIMENT CORPS.

WILLET M. HAYS, M. Agr.,	Agriculturist.
SAMUEL B. GREEN, B. S.,	Horticulturist.
‡OTTO LUGGER, Ph. D.,	Entomologist and Botanist.
HARRY SNYDER, B. S.,	Chemist.
T. L. HÆCKER,	Dairy Husbandry.
M. H. REYNOLDS, M. D., V. M.,	Veterinarian.
THOS. SHAW,	Animal Husbandry.
ANDREW BOSS,	Asst. in Agr., University Farm.
T. A. HOVERSTAD, B. Agr.,	Superintendent, Crookston.
R. S. MACKINTOSH,	Asst. in Hort., University Farm.
H. H. CHAPMAN, B. S., B. Agr.,	Superintendent, Grand Rapids.
E. W. MAJOR, B. Agr.,	Assistant in Dairy Husbandry.
J. A. HUMMEL, B. Agr.,	Assistant Chemist.

‡Deceased.

INFLUENCE OF WHEAT FARMING UPON SOIL FERTILITY.

HARRY SNYDER.

Outline of Bulletin. This Bulletin is a continuation of experiments reported in Bulletin No. 53 relating to the influence of continuous wheat culture and the rotation of crops upon the composition and fertility of soils. A field of uniform character of soil was divided, in the spring of 1892, into six plots. The soil was in fair condition of fertility but was somewhat reduced by continuous wheat cropping. After the removal of one crop of wheat from each of the plots to test the soil as to uniformity, samples of soil were taken for chemical analysis. From each of the plots at definite points, five lots of soil were taken with a post hole auger to a depth of nine inches, and a compound sample for analysis was made by mixing equal parts of the five samples from each plot. Four years later, 1897, after the various plots had been subjected to different methods of culture, samples were again taken for analysis. The records of the crop yields and the increase and decrease of fertility, particularly of the nitrogen and humus of the soil, are all recorded in Bulletin No. 53. Four years later, 1901, or eight years after the beginning of the experiment, samples were again taken from the plots and analyzed with the object of determining the influence which continuous wheat culture and the rotation of crops have had upon the fertility and composition of the soils and the influence which the different systems of culture have had upon

the fertility. The results of this work are recorded in this bulletin.

Description of Plots. Plot No. 1, four rods by five rods, has been in wheat continuously for eight years and the yields, per acre, have varied from 8.9 bushels in 1894 to 25.2 bushels in 1898 when the conditions of rain fall and climate were particularly favorable. No manure or fertilizer has been used; the land has been fall plowed annually and in the spring sown to wheat. Upon plot No. 2, a rotation consisting of wheat, clover and other cereals has been followed. Owing to climatic conditions, particularly as to rainfall, it has not been possible to follow out the rotation intended. In 1893 wheat was grown and the land was seeded to clover, after the removal of a clover crop in 1894, a wheat crop was obtained in 1895 and oats in 1896. A crop of wheat was harvested in 1897 and clover was sown with the wheat. In 1898 a crop of clover was harvested, and this was followed by two crops of wheat. During the eight years of cultivation, five crops of wheat, one of oats and two of clover have been removed. Instead of wheat continuously, clover is introduced into the rotation once in four years. On plot No. 3, the rotation consists of oats, clover, barley, corn and manure. On plots 4, 5 and 6 respectively, corn, oats and barley are grown continuously. These rotations are not given as rotation models, for the most suitable rotations for different purposes can be determined only after more extended investigations. Experiments of this nature are now being conducted by this Experiment Station.

Description of Soil. The soil of the six plots was uniform in character and chemical analyses showed but little variation in the nitrogen content. The soil would ordinarily be described as a loam resting upon a clay sub soil under laid, at a greater depth, with gravel. Chemical analyses have shown the soil to be well supplied with the mineral elements of fertility and with a fair amount of nitrogen and decaying animal and vegetable matter in the form of humus. In these

experiments particular attention was given to the nitrogen and to the humus material, because previous investigations and experiments have shown that the decline in the yield of wheat on old soil is due more to the loss of nitrogen and decaying animal and vegetable matter of the soil (humus) than to any other cause.

TABLE I.—Chemical Composition of Soil.

	Surface Soil Per cent	Sub Soil Per cent
Insoluble matter	84.08	84.55
Potash (K_2O)	.30	.38
Soda (Na_2O)	.25	.21
Lime (CaO)	.51	.34
Magnesia (MgO)	.26	.29
Aluminia (Al_2O_3)	4.24	5.61
Iron oxide (Fe_2O_3)	2.56	3.40
Phosphoric acid (P_2O_5)	.23	.21
Sulphuric acid (SO_3)	.06	.08
Carbonic acid (CO_2)	.29	.02
Volatile matter	7.68	4.61

TABLE II.—Physical Composition of Sub Soil.

	Size of Particles Inches		Per cent
Medium sand	.02	to .01	1.20
Fine and very fine sand	.01	to .002	4.14
Silt	.002	to .004	44.35
Fine silt	.004	to .0002	30.75
Clay	.0002	and less	15.45
Volatile matter			4.61

YIELDS OF PLOTS.

TABLE III.—Plot No. 1.

Year		
1893	Wheat, No. of bushels per acre	12.3
1894	" " " "	8.9
1895	" " " "	17.3
1896	" " " "	14.1
1897	" " " "	10.2
1898	" " " "	25.2
1899	" " " "	17.6
1900	" " " "	18.8
	Average	15.55

During the eight years this plot (No. 1) has produced an average of 15.55 bushels per acre of wheat. Under the most favorable conditions of climate and rainfall this plot produced twenty-five bushels per acre of wheat. The variations in the yield per acre are noticeable and vary with the climatic conditions. The yields are closely related to the amount of rainfall particularly in the early spring.

TABLE IV.—Plot No. 2.

1893	Wheat, No. of bushels per acre	13.7
1894	Clover, lbs. per acre	4320
1895	Wheat, No. of bushels per acre	22
1896	Oats, " " "	31.4
1897	Wheat, " " "	14.2
1898	Clover, lbs. per acre	2820
1899	Wheat, No. of bushels per acre	19.5
1900	" " " "	24.4

The influence of clover in the rotation upon the yield of wheat is noticeable. In 1895, 4.7 bushels more per acre were obtained from this plot, after a clover crop, than was secured from plot No. 1 which had been in wheat continuously, while

in 1900, the second year after the clover crop, 5.6 bushels more per acre were secured. In fact a larger yield of wheat was obtained the second year after the clover than the first year. The average yield of wheat from plot No. 2 was 18.75 bushels per acre. The average yield for the same years on plot No. 1 was 15.55 bushels. In 1893 the difference in the crop producing power between plots No. 1 and 2 was 1.4 bushels of wheat, while in 1900, after two clover crops had been grown, the difference was 5.6 bushels in favor of plot No. 2.

TABLE V.—Plot No. 3.

Year		
1893	Oats, No. of bushels per acre	46.1
1894	Clover, lbs. per acre	2360
1895	Barley, No. of bushels per acre	42.5
1896	Corn, " " "	66.7
1897	" " " "	33.7
1898	Oats, " " "	76.4
1899	Clover, lbs. per acre	3720
1900	Barley, No. of bushels per acre	28.3

On this plot oats, barley and corn have been grown in place of the wheat on plot No. 2. The clover of plot No 3 more noticeably influenced the yield of corn than the yield of either oats or barley. In 1896, 22.3 bushels more of corn per acre were obtained from plot No. 3 than from plot No. 4 upon which corn was grown continuously. In 1900 the lack of rain in the spring and early summer reduced the yield of barley materially, the crop was too far advanced to be benefited by the late rains as in the case of the wheat. Nevertheless on plot No. 3 where clover and corn had been grown, the yield of barley was 28 bushels per acre, while on plot No. 6 it was practically a failure. The oats grown in rotation upon plot No. 3 yielded, in 1898, 18.4 bushels per acre more than on plot No. 5 where oats were grown continuously. In the be-

ginning of the experiment there was a difference of less than 4 bushels per acre in the yield of oats from plots 3 and 4, while in 1898 after the removal of a clover and barley crop and a light dressing of manure, an increase of 18.6 bushels of oats per acre was secured on plot No. 3. Upon plots 4, 5 and 6, corn, oats and barley were raised continuously. The yields per acre for these plots are given in tabular form in the following table.

TABLE VI.—Yields per acre of Corn, Oats and Barley Grown Continuously Upon Separate Plots.

Year	Plot No. 4 Corn, bu.	Plot No. 5 Oats, bu.	Plot No 6 Barley, bu.
1893	50	42.5	28
1894	33.3	27	18.5
1895	75.5	54.1	39
1896	44.4	31	35.6
1897	10	31	28.1
1898	30.5	56.2	40.3
1899	....	24.7	26.7
1900	42.2	11.2	2.6
Average	40.84	34.81	27.35

The yields of corn, oats and barley on plots Nos. 4, 5 and 6 respectively range between quite wide limits. The low yield of oats and barley in 1900 was due to the unusually dry spring and early summer. As in the case of the wheat yields of plots Nos. 1 and 2, the yields of oats, barley and corn from plots Nos. 4, 5 and 6 have been influenced by the rainfall more than by any other factor. On all of the plots where grain has been grown continuously considerable trouble has been experienced with weeds, as no opportunity is offered for their eradication. In fact the low yields of grain have, in part, been due to the vigorous growth of weeds. The average yields of corn, oats and barley from plots Nos. 4, 5 and 6 are materially less than are obtained from many well

regulated farms in the state but they are no less than are secured from farms where grains are grown continuously, and where no opportunity is afforded for eradication of weeds and the addition of humus to the soil.

Losses of Nitrogen from the Soil. In discussing the losses of plant food from the soil, particular attention is given to nitrogen. This element is combined with, and forms a part of, the animal and vegetable residue of the soil. Previous experiments have shown (Minn. Ex. Sta. Buls. 30, 41, 53 and 65) that in grain cultivated soils there is a rapid decline of the vegetable and animal matter, and also a liberation and loss of the element nitrogen which is one of the most valuable elements of plant food. As long as the nitrogen is in combination with and forms a part of the humus or decaying animal and vegetable matter of the soil it is in a stable form, but as soon as the humus decays, the nitrogen is liberated in various gaseous and soluble forms which are easily lost from the soil. The value of nitrogen as a plant food has been discussed in former bulletins. Briefly stated, however, it is one of the most essential elements of plant growth; in its absence no plant can mature, and when present in restricted amounts crops fail to make good yields. Nitrogen enters into the growth of every plant cell, it is one of the elements which make up the chlorophyll or green coloring matter of the plant and it is also the chief element of which the gluten and nitrogenous compounds are composed.

Because of its forming a part of the animal and vegetable matter of the soil, there is no element that is so readily lost as nitrogen. It is not possible for the mineral forms of plant food, as potash and phosphoric acid to be converted into gaseous and soluble forms by the ordinary chemical changes which take place in the soil as in the case of nitrogen. The main loss, which the mineral elements of the soil suffer, is in their removal by crops as food. With the nitrogen of the soil there is a loss not only of what is assimilated and removed by crops, but also a loss by the decay of the humus and the

liberation of the nitrogen in gaseous and soluble forms. One of the chief causes of the decline in fertility of old grain soils is this loss of nitrogen by the rapid decay of the animal and vegetable matter of the soil, which has been accelerated by the continuous cultivation of grain.

The Determination of Nitrogen. Since nitrogen is of so much importance in plant growth, it is essential that 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 lbs. of dry soil there are .222 lbs 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 the case of these experiments the loss of nitrogen, as pointed out, has been due to the decay of the humus and dissipation of the nitrogen. The gain of nitrogen has been due to the assimilation of the free nitrogen from the air by micro-organisms associated with the roots of the clover. This assimilation of atmospheric nitrogen is of very great importance and the discovery, by Hellreigel and others, of the unique value of clover and leguminous plants in adding nitrogen to the soil and therefore increasing its fertility, has been one of the greatest achievements of agricultural chemistry.

Loss of Nitrogen by Continuous Wheat Cultivation. Plots Nos. 1 and 2 contained, at the beginning of the experiment in 1892, .221 per cent of nitrogen, while plots Nos. 3, 4, 5 and 6 contained .211 per cent. It is estimated that an acre of the soil of plots Nos. 1 and 2, to a depth of nine inches, would contain approximately 7,700 lbs of nitrogen, while the remaining plots would contain approximately 7,400 lbs. At the end of the first four years of continuous wheat cul-

tivation, plot No. 1 contained .193 per cent of nitrogen; a loss of .028 per cent, equivalent to an annual loss of 171 lbs. of nitrogen per acre. At the end of the second period of four years, the soil contained .173 per cent of nitrogen. This is an additional loss of .02 of a per cent, or a total loss of .048 per cent nitrogen for the entire period. During the eight years of continuous soil cultivation the total nitrogen has been reduced from .221 per cent to .173 per cent. This is equivalent to 21.72 per cent of the total nitrogen in the soil. That is, during the eight years, more than one-fifth of the original stock of nitrogen in the soil has been lost. The amount of nitrogen removed in the crop has not exceeded 40 lbs. per acre and while the total loss of nitrogen amounts to more than 1,700 lbs., the actual amount removed in the grain crop does not exceed 300 lbs. Thus of the 1,700 lbs. of nitrogen lost during the eight years of continuous wheat cultivation, 300 lbs. only have been utilized by the wheat as plant food and 1,400 lbs. have been lost by the decay of the humus and the conversion of the nitrogen from insoluble and stable humic forms to gaseous and soluble forms which are readily lost. This heavy loss of nitrogen from the soil has resulted in gradually reducing the wheat producing power of the soil. Plot No. 1, at the end of eight years of continuous wheat cultivation, produced 5.6 bushels per acre less wheat than plot No. 2, which had produced five crops of wheat, two of clover and one of oats. Similar losses of nitrogen from old wheat soils are reported in bulletins Nos. 30, 41, 53 and 65 of this Station. If purchased in commercial forms, this nitrogen would cost at least 14 cents a pound for its return to the soil.

Loss of Nitrogen During a Rotation. At the beginning of the experiment in 1892, plot No. 2 contained .221 per cent of nitrogen. At the end of the eight years, after the removal of five crops of wheat, two of clover and one of oats, or six grain crops and two clover crops, the soil contained .198 per cent of nitrogen. During the first four years of the experi-

ment there was a gain of nitrogen; during the last four years there was a loss. The first clover crop was much heavier and more even than the second crop. During the eight years the soil lost .023 per cent of nitrogen equivalent to 10.41 per cent of the total nitrogen of the soil. That is, during the experiment approximately 800 lbs. of nitrogen were lost from the soil. It is estimated that the eight crops removed about 300 or 350 lbs. of nitrogen from the soil, the remaining 450 or 500 lbs. were lost by oxidation and decay of the humus of the soil. Compared with plot No. 1 it will be observed that the loss of nitrogen from plot No. 2 was less than half as great. When wheat was grown continuously for eight years on plot No. 1, approximately 1,700 lbs. of nitrogen were lost from the soil. When two crops of clover, five of wheat and one of oats were obtained from plot No. 2 the total loss of nitrogen was less than 800 pounds. The two crops of clover during the eight years reduced the losses on plot No. 2 and resulted in a saving of nitrogen to the extent of 900 lbs per acre. This additional amount of fertility of plot No. 2 has resulted, as previously stated, during the last year of the experiment, in an increase of 5.6 bushels per acre of wheat.

On plot No. 3 oats, clover, barley and corn have been grown. The soil of this plot originally contained .211 per cent of nitrogen. At the end of eight years the soil contained .198 per cent of nitrogen. Thus during the rotation, the soil lost .013 per cent of nitrogen, equivalent to about 6.2 per cent of the total nitrogen of the soil or 450 lbs. It is estimated that the eight crops removed from the soil from 350 to 400 lbs of nitrogen which makes the loss of nitrogen from the decay of the humus less than a hundred pounds.

The total losses of nitrogen from the three plots, when compared, show that when wheat was grown continuously for eight years there was a loss of over 1,300 lbs. in addition to that required for the growth of the crop. From plot No. 2, which produced five crops of wheat, one of oats and

two of clover, the total loss of nitrogen, in addition to that removed in the crop, was 450 lbs., while from plot No. 3, which produced two crops each of oats, barley and corn and received two dressings of manure, the loss of nitrogen in addition to that removed by the crops was less than a hundred pounds. It is evident that the continuous cultivation of small grains is particularly favorable to the destruction of the nitrogen of the soil, but this loss can be checked by the occasional growth of clover and the use of farm manure.

Because of the large stock of nitrogen originally present in the soil the loss of 21.72 per cent of this total amount has not as yet caused a sufficient poverty in available nitrogen to seriously affect the yield of grain. Nevertheless the loss is excessive and there is no necessity for its occurrence, and sooner or later this loss of the most valuable element of plant food will make itself felt.

Loss of Nitrogen by the Continuous Cultivation of Corn, Oats or Barley. On plot No. 4 corn was grown continuously. The soil contained originally .211 per cent nitrogen and at the end of eight years .189 per cent of nitrogen. The .022 per cent loss of nitrogen is equivalent to 10.43 per cent of the total nitrogen of the soil or about 760 pounds per acre. Corn culture appears to be less destructive to the humus and nitrogen of the soil than exclusive wheat culture. During the eight years of wheat cropping the soil lost 21.72 per cent of its total nitrogen, while 10.43 per cent was lost during the same period of corn culture. A corn crop, however, requires more nitrogen for food purposes than does a wheat crop, but when corn is grown there appears to be less nitrogen lost from the soil. It has been frequently observed that after a corn crop has been grown on wheat land a better yield of wheat is obtained. This is due to the fact that a part of the nitrogen, liberated during the growth of the corn, is conserved and is in more available condition for the wheat. The high value of corn in a grain rotation has been recognized by many farmers.

When oats were grown continuously on plot No. 5 there was a loss of .026 per cent of nitrogen or 17.07 per cent of the total store of nitrogenous plant food in the soil. In the case of barley grown on plot No. 6 the total loss of nitrogen, during the eight years, amounts to 18.94 per cent of the total nitrogen of the soil. When oats and barley are grown continuously the conditions for oxidation and destruction of the humus and loss of nitrogen are quite similar to those in the continuous cultivation of wheat. The losses of soil nitrogen from plots Nos. 5 and 6, due to the continuous cultivation of oats and barley, are, as in the case of the continuous wheat cultivation on plot No. 1, excessive.

Losses of Humus. There was a decrease in the humus content of all the soils upon which grain was grown continuously. Earlier experiments have shown that one part of nitrogen corresponds to about ten or twelve parts of humus, and that any increase or decrease of the soil nitrogen was followed by a corresponding increase or decrease of humus. The methods for the determination of humus do not, at the present time, admit of as great accuracy as the methods for the determination of nitrogen, therefore it is not possible to measure the absolute loss of humus with the same precision as the loss of nitrogen. The soil originally contained about 3.3 per cent of humus materials and 7.68 per cent of total volatile matter. The total volatile matter consists of humus and other forms of animal and vegetable matter, water of hydrated silicates, etc. The soil of plot No. 1, after eight years of continuous wheat cultivation, contained less than .3 per cent of humus and 7.07 per cent of total volatile matter. Of this loss of volatile matter, .61 per cent is due to the decay of the animal and vegetable materials and humus of the soil. Plots Nos. 4, 5 and 6, which produced corn, oats and barley respectively, sustained a similar loss of humus to plot No. 1. Plots Nos. 2 and 3, which produced clover in rotation with the grains, contained about the same amount of volatile matter and humus at the end of

eight years as at the beginning. When wheat, oats, corn and barley were grown continuously no new stores of vegetable or animal materials for humus formation were added to the soil. Continual cultivation without restoraton has resulted in a gradual decline of the humus materials of plots Nos. 1, 4, 5 and 6. On plots Nos. 2 and 3 the rotation and residue from the clover crops have resulted in practically maintaining an equilibrium of the humus content of the soil.

It is estimated that the soils of plots Nos. 1, 4, 5 and 6, upon which grain crops have been grown continuously, have sustained a total loss of over 17,000 lbs per acre of humus or an annual loss of over a ton of humus. Previous experiments, upon the composition of native and cultivated soils and the effects of continuous grain cultivation upon their fertility, have shown similar losses of humus. (Minn. E. Sta. Bul. No. 30.)

The loss of humus from the soil has not only reduced the stock of nitrogen but has also reduced the amount of available mineral plant food of the soil. The decaying animal and vegetable matter of the soil produce acids which act upon the inert and inactive plant food elements and render them available. The humates or organic products formed by the union of the organic acid products from the decay of the humus, and the mineral matter of the soil, are valuable forms of plant food. Former experiments of this Station (Minn. Ex. Sta. Buls. 41, 65) have shown that humates are capable of being assimilated and utilized as plant food. Potash, phosphoric acid, and all of the mineral elements of plant food when combined with humus are valuable forms of food for grain crops. The high fertility of the prairie soils is due to their mildly alkaline character and their large stores of humus. The destruction of the humus by unnatural systems of farming, as continuous grain culture, has temporarily reduced the crop producing power of many soils. This is only a temporary and not a permanent injury. As soon as some humus producing materials are returned to the soil

it regains a large part of its former crop producing capacity as shown in these experiments.

Summer Fallowing Causes a Loss of Both Nitrogen and Humus. Adjoining plot No. 1 a strip of land was summer fallowed for two years in succession. Originally the soil contained .221 per cent nitrogen and at the close of the second season of bare fallow .201 per cent. The loss of .02 per cent of nitrogen during the two years is equivalent to about 600 lbs. per acre or over ten times more than would be required by two crops of wheat.

Summer fallowing is more destructive to the humus and nitrogen than continuous grain cultivation, and when summer fallowing is alternated with grain growing the most favorable conditions exist for rapid depletion of the soil nitrogen. It is true that a large yield per acre of wheat can be secured after fallowing the land, but this increase is at the expense of rapidly depleting the soil of its most valuable element of fertility—nitrogen—and in time will be followed by a decrease in yield. When summer fallowing is practiced, the humus and other forms of animal and vegetable matter of the soil undergo, in our mildly alkaline soils, rapid decay and the succeeding crop of wheat feeds upon only a small part of this nitrogen that has been liberated. When summer fallowing is practiced it is estimated that for every pound of nitrogen utilized by a wheat crop for food, six pounds are lost from the soil in other ways.

Influence of Humus upon the Physical Properties of Soils. The loss of humus, due to continuous grain cultivation, has changed the physical properties of the soil as color, weight per cubic foot, and relation of the soil to water. The soils which have produced small grains continuously are lighter in color than the soils which have produced grain and clover in rotation. Soils from plots Nos. 2 and 3, which have produced grain and clover in rotation, can readily be distinguished from plots Nos. 1, 4, 5 and 6 which have produced grain crops continuously.

TABLE VII.—Moisture Contents of Soils, 1901.

1900	Wheat Continuous Per Cent	Rotation. Water Per Cent	Corn. Water Per Cent
June 15	11.01	12.72	17.27
June 20	10.25	11.01	16.04
June 27	8.77	9.58	16.60
July 6	22.98	23.35	23.07
July 11	17.20	18.56	19.09
July 18	18.02	19.07	20.68
July 25	15.09	14.70	18.92
August 2	9.28	10.91	16.81
August 8	15.70	14.19	16.89
August 15	17.80	17.14	18.76
August 20	15.69	17.38	20.67
August 22	18.36	19.9	18.69
September 1	15.04	17.67	17.21
September 15	23.00	24.88	23.93
September 21	21.39	22.49	21.33
September 27	22.36	23.53	20.96
October 6	24.93	24.04	22.71
1901			
April 20	28.4	25.69	23.44
May 1	21.33	21.64	20.9
May 10	20.38	21.96	18.85
May 15	19.93	20.4	20.22
May 25	21.23	21.18	20.47
May 30	17.83	18.66	20.17

Moisture Content of Soils. The influence which the loss of humus has had upon the moisture content of these soils is noticeable. In former bulletins it has been stated that a loss of humus has resulted in a proportional loss of the capacity of the soil to retain water. The extremely dry spring and early summer of 1900 gave an unusual opportunity to study the influence of the rotation of crops, and continuous cultivation of wheat upon the moisture content of soils. In 1900, plots Nos. 1 and 2 produced wheat. Upon plot No. 1 wheat had been grown continuously, while on plot No. 2 wheat and other grains and clover had been grown in rotation. Plot No. 2 contained about .50 per cent more humus than plot No. 1. On plot No. 4 corn was grown. From table No. 7 it will be observed that prior to July 1st, plot No. 2 contained, to the depth of nine inches, appreciably more water than plot No. 1. The effect of the additional humus in plot No. 2 in conserving the soil moisture is marked. At the time the soils reached their lowest point in moisture content, plot No. 1, the continous wheat rotated plot, contained 8.77 per cent of water, while plot No. 2 contained 9.58 per cent.

Occasionally plot No. 1 contained a little more water than plot No. 2. This usually occurred after heavy rainfalls, and before an equilibrium of the soil moisture was established. The higher per cent of moisture at such times was followed by rapid evaporation resulting in a subsequent loss of water. At the times that the soil moisture was most needed and when the lack of rain was most severely felt plot No. 2 always contained more water than plot No. 1.

The value of shallow surface cultivation in conserving the soil moisture is shown in plot No. 4 upon which corn was grown. During the period of severe drouth the corn land contained from 5 to 7 per cent more water than the wheat land. At the time when plot No. 1 contained the least water, 8.77 per cent, June 27, 1900, plot No. 2 contained 16.60 per cent. At other times during the year the differences

were less marked. The conservation of the soil moisture by the shallow cultivation of corn land is felt more than one year. When wheat follows corn there is always a better supply of moisture in the soil for the next wheat crop.

Wheat Not Necessarily an Exhaustive Crop. By many, wheat is considered an exhausting crop, and it is believed that it makes heavy drafts upon the fertility of the soil. The way it is usually cultivated does impair fertility. The experiments that have been made show, however, that it is not the crop itself that is responsible for the loss of nitrogen and the decline in fertility, but the method, or, rather, lack of systematic method, of cropping that has been followed. When wheat is raised in a rotation it is not a soil depleting crop, but when raised continuously large amounts of nitrogen are lost, not through the crop, but by the decomposition of the nitrogenous humus. While many wheat farms of the northwest have lost large amounts of nitrogen, the soils are by no means depleted of their nitrogen. The Rothamsted soil which has raised over 50 crops of wheat continuously, and without fertilizers contains only about .09 per cent nitrogen, while many of the wheat soils of the northwest that have produced 20 or more wheat crops contain .20 per cent nitrogen. When properly grown in a rotation, wheat is not an exhaustive crop, it takes less plant food from the soil than many farm crops. (Minn. Ex. Sta. Buls. Nos. 29 and 47.) It is the method, not the crop, which has caused the decline of fertility.

The use of commercial fertilizers as a means of returning the fertility to the soil has been proposed and tried. The experiments that have been made by this Station, (Minn. Ex. Sta. Bul. No. 22) show that commercial fertilizers cannot be used economically in the production of large areas of wheat in the northwest. The only feasible way of making old wheat lands more productive is to rotate the crops, growing some leguminous crop, use farm manures, and practice more thorough cultivation. On some farms, wheat has been

raised in a systematic rotation, and farm manure has been liberally and intelligently used. On such farms no decline in yield per acre has been observed. In fact, upon some of these farms where wheat has been systematically grown, larger yields per acre are now secured than when the land was first brought under cultivation.

In some localities millet is grown as a green manurial crop, and then wheat follows the millet. This method has been found to give good yields. The millet increases the stock of organic matter in the soil and prevents a rapid decline of the nitrogen. There is need, in the Northwest, of growing leguminous crops for green manurial purposes.

The fact that the wheat soils "recuperate" so easily when given the right culture, and that the loss of nitrogen can be checked and even increased by a rotation of crops makes the outlook for wheat production even better than it has been. By the application of more rational methods to wheat farming larger yields and a better quality of wheat can be secured and the fertility of the soil conserved.

CONCLUSIONS.

1. When wheat was grown continuously upon the same soil for eight years, there was a loss of 1,700 pounds per acre of nitrogen, about 300 pounds being utilized as plant food and 1,400 pounds lost by the decay of the animal and vegetable matter of the soil and the liberation of the nitrogen as gaseous and soluble compounds. During the eight years of continuous wheat cultivation there was a loss of over 21 per cent of the total nitrogen of the soil, equivalent to an annual loss of 175 pounds per acre in addition to that used as plant food.

2. When wheat was grown in a rotation with clover and oats, five crops of wheat being removed in eight years, larger yields per acre were secured and the total loss of nitrogen from the soil was reduced to 800 pounds or about 450 pounds

in excess of that utilized as plant food. When corn was grown with clover and oats in a rotation and farm manure was used, the total loss of nitrogen from the soil, for eight years, was less than one hundred pounds in excess of that removed as plant food.

3. When the oats and barley were grown continuously the losses of nitrogen from the soil were nearly as large as when wheat was grown continuously.

4. When corn was grown continuously the loss of nitrogen from the soil was less than half as large as when wheat was grown continuously. When corn is introduced into a rotation of crops, the losses of nitrogen are less than if wheat were grown.

5. When wheat was grown continuously there was an annual loss of over 2,000 pounds per acre of humus due to the fermentation and decay of the animal and vegetable matter of the soil. When wheat was grown in a rotation with clover and oats, no material loss of humus from the soil occurred.

6. The loss of humus changed the physical properties of the soil, causing it to be less retentive of moisture, lighter in color, and heavier in weight per cubic foot. During times of drought the soil from the continuous wheat cultivated plot contained less water than the soil from the plot which produced wheat in rotation with clover. Humus conserves the moisture of the soil, while the rotation of crops, the use of farm manures and the growing of clover, conserves the humus of the soil.

7. When bare summer fallowing is practiced, a heavier loss of nitrogen occurs than when wheat is grown continuously. Summer fallowing favors the decay of the humus and the loss of nitrogen. While larger crops of wheat are produced after a year of fallow, this increase is followed by a heavy loss of the total nitrogen of the soil. Summer fallowing rapidly exhausts the soil of its nitrogen.

8. When the nitrogen and humus of the soil were conserved by the rotation of crops and the production of clover, an increase of 20 bushels per acre of corn, and 5.6 bushels of wheat were secured.

9. Wheat is not an exhaustive crop when it is grown in a rotation, but when it is grown continuously the fertility of the soil is impaired. It is not the crop itself that reduces the fertility, but it is the lack of systematic methods of farming which cause the decline of fertility. Old wheat soils readily recuperate when some humus forming materials are returned to the soil. By the rotation of crops, the use of farm manures and the cultivation of clover the heavy losses of nitrogen and humus from the soil can be checked, and larger yields and a better quality of wheat secured.