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The Relation of Different Systems of Crop Rotation to Humus and Associated Plant Food

BY

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LETTER OF TRANSMITTAL.

MINNESOTA EXPERIMENT STATION,
Division of Agricultural Chemistry and Soils.
University Farm, St. Paul, Minn., April 6, 1912.

Sir: I have the honor to transmit herewith the manuscript of an article entitled The Relation of Different Systems of Crop Rotation to Humus and Associated Plant Food, by G. W. Walker of this Division, and to recommend its publication as Bulletin No. 128 of this station.

The work reported in this article is a continuation of the investigations reported in Bulletin 109 of this station in which the effect of different systems of cropping upon the available plant food, total nitrogen and carbon of the soil was studied.

The practical importance of maintaining the humus content of the soil is generally recognized, but there is much need for more exact scientific knowledge, not only regarding the chemical nature of humus, but particularly in regard to its relation to the mineral matter of the soil, especially as affected by different systems of cropping.

The work reported in this article throws much valuable light on the subject.

Very respectfully,
RALPH HOAGLAND,
Chief of Division.

MR. A. F. WOODS,
Director of Experiment Station.

CONTENTS

Humus and Crop Rotation

INTRODUCTION.

This investigation has been undertaken for the purpose of finding what relation, if any, exists between the humus content of the soil and various systems of crop rotation; also, to find whether there is any relation between the systems of cropping practiced and the changes in the amount of nitrogen, phosphoric acid and potash associated with the humus. An attempt has been made to find the relative proportion of the nitrogen, phosphoric acid and potash associated with the humus, as compared with the total nitrogen, phosphoric acid, and potash found in the soil.

In the following discussion it will be noted that the term humus has been used in various ways, depending on the point of view of the investigator. King[1] says: "Beds of peat and the black muck soils are the best examples of what is meant by humus." Hilgard[2] considers vegetable mold resulting from the decay of vegetable matter as humus. Hopkins[3] says: "The term humus is not synonymous with organic matter. Humus includes only that part of the organic matter that has passed the most active stage of decomposition and completely lost the physical structure of the materials from which it is made, and has become as a rule thoroughly incorporated with the soil mass." Agronomists generally use the term humus to designate the partly decomposed organic matter of the soil, while some use the term humus as synonymous with organic matter. Agricultural chemists are now quite generally agreed in using the term humus to designate that portion of the organic matter of the soil soluble in dilute solutions of ammonia and sodium hydroxide, the lime and magnesia having been previously removed by treatment with dilute hydrochloric acid. In the latter sense the term humus is used in the experimental part of this investigation.

The author acknowledges his indebtedness to Prof. R. Hoagland and to Mr. W. H. Frazier for suggestions offered in course of the work, and also to Mr. P. R. McMiller for making part of the potash determinations.

1. The Scil p. 95 (1908).
2. Soils, p. 21 (1910)
3. Soil Fertility and Permanent Agriculture, p. 194 (1910)

I. THEORETICAL AND HISTORICAL

(a) Physical Properties of Humus.

An investigation of the relation of different systems of crop-rotation to humus necessarily involves a preliminary consideration of its properties. The physical and physico-chemical properties of humus are deserving of more systematic study than they have hitherto received.

Increasing attention is being given to the nature of the chemical compounds entering into the composition of humus, and to the influence of these compounds upon the growth of plants.

The physical properties of humus undoubtedly have considerable influence in crop-production. Petit[1] has shown that the passage of frost into the ground is slowest in the case of humus (peat). The specific heat[2] of a muck soil (25% organic cmactetcer) is found to be 0.1566 as compared with 0.1828 for Podunk fine sandy loam, and 0.1900 for large quartz grains and fine quartz flour. The heat-conductivity[3] K' for a muck soil is found to be 0.000349 (C. g. s. units) as compared with 0.000792 for Podunk fine sandy loam, and 0.000917 for coarse quartz. The heat conductivity K' of water is 0.00149 as given by Lees. There is evidently, then, a direct relationship between the low specific heat of soil organic matter and its lower heat-conductivity and slowness in permitting the passage of frost.

Schubler[4] found the absorptive capacity of soils for water-vapor, per 1000 parts of soil in a nearly saturated atmosphere, during 24 hours, to be as follows: Quartz sand, coarse, 0; clay soil (60 per cent clay), 28; loam, 35; garden mold (7 per cent humus), 52; humus, 120. The investigations of Patten & Gallagher[5] show that, although the presence of organic matter has a marked effect in increasing the water-holding capacity of soils, it does not decrease the rate of evaporation.

According to Reichardt and Blumtritt,[6] the atmospheric gases absorbed, per 100 grams of soil, were: Peat, 162 cc.; garden soil, 14 cc.; and river silt, 40cc. In each case the percentages of nitrogen

1. Bul. No. 59, Bureau Soils, U. S. Dept. Agr. (1909) p. 10.
2. Ibid p. 34.
3. Ibid p. 50.
4. Bul. No. 51, Bureau Soils, U. S. Dept. Agr. (1908) p. 11.
5. Ibid pp. 49 and 19.
6. Bul. No. 51, Bureau Soils, U. S. Dept. Agr. p. 26.

and carbon dioxide were much in excess of the percentage of oxygen, the probable explanation being the conversion of the oxygen of the absorbed air into carbon dioxide; the percentage of the latter being, for peat, 51%; for garden soil, 33%; for river silt, 32%.

Ammon[1] found that humus absorbed, at 20° C., 11.5 per cent of its dry weight of ammonia; while under the same conditions quartz powder absorbed 0.295, and kaolin 0.42.

Stellwagg[2] found that when water vapor was absorbed the temperature rose as follows: Quartz sand, 0.88°C; quartz powder, 1.08°C; kaolin, 2.63°C; peat, 12.25°C.

Blanck[3] reports experiments showing that the presence of acid humus compounds in the soil hinders the diffusion of water. This is denied by Minssen,[4] who claims that neither humus acids, other organic acids, or mineral acids, interfere with the diffusion of water or salt solutions.

According to Hilgard,[5] natural humus has a density of about 1.4 and a volume-weight of 0.3349. Saturated with water, its volume is increased 209.2 per cent of its air-dry volume. Accordingly, of the soil constituents, humus has the least density and volume-weight, and gives the greatest increase in volume on saturation with water.

Davis[6] has shown that humus decreases the electrical conductivity of a soil.

Pankov,[7] from determinations of humus in soils of different plats, showed that, the finer the particles of the soil, the greater the humus content; the water-soluble humus in light and open soils being higher than in heavy soils. Schloesing[8] found the following amounts of organic matter adhering to the soil particles: In one soil, 0.4% in coarse sand and 5.46% in the clay; in another soil, 0.15% in coarse sand and 4.14% in the clay.

In regard to (a) its density, specific heat, heat conductivity, water holding capacity, volume weight, rise in temperature on saturation with water, and relation to electrical conductivity, (b) absorptive capacity for water vapor, the atmospheric gases, ammonia and salt solutions, "humus" is seen to occupy a predominant place among the constituents of the soil. From its physical properties alone, "humus"

1. Bul. No. 51, Bureau Soils, U. S. Dept. Agr. p. 29.
2. Bul. No. 51, Bureau Soils, U. S. Dept. Agr. p. 47.
3. Experiment Sta. Record, 14, p. 848 (1902-3).
4. Landw. Vers. Stat. 62 (1905) p. 476.
5. Soils, p. 125 (1910).
6. Trans. Amer. Electrochem. Soc. 17 (1910) pp. 391-403.
7. Experiment Sta. Record, 24, p. 318 (1911).
8. Comp. Rend. Acad. Sci. Paris 135 (1902), p. 603.

has, then, a very marked effect upon the physical properties of the soil, in proportion to the amount present, and must correspondingly affect crop-production.

(b) Physico-Chemical and Chemical Properties of Humus.

Some investigations apparently indicate that the chemical effects brought about by "humus" are physico-chemical rather than purely chemical. According to Van Bremmelen,[1] humus substances have a colloidal solubility, and form absorption complexes with acids and salts, but most easily with bases. In this way we may account for the so-called acid properties of "humus."

J. Dumont[2] found, on shaking up soils with a solution of mono-calcium phosphate, that absorption was greater in humus soils containing a variable amount of lime than in ordinary soils, and that the removal of humus by ignition greatly reduced the absorptive capacity. He concludes that the greater the proportion of humus to lime the greater the absorption, and that an abundance of humus reduces the amount of reversion. Hall and Gimingham[3] conclude: "It seems certain, however, that free 'humic' acid can to some extent decompose ammonium salts with the formation of an insoluble ammonium compound." Morse[4] states that he has obtained similar results with potash salts; lime passing into the solution on the addition of humus, accompanied by a disappearance of potash; "showing that the potash must have been combined."

Doyarenko[5] investigated the way in which humic acids absorb nitrogen, using a 10% sol. of ammonium salt, and found that the absorbed nitrogen almost exclusively gave rise to the formation of amids; the amount of absorbed nitrogen being the same in all cases.

Berthelot[6] reports a two days treatment of fresh humic acid with a dilute solution of potassium chloride and ammonia; which gave an almost neutral solution and a compound containing 3.22% of potash, insoluble in cold water. Of 11.75 parts of potash used, 3.21 parts became insoluble, and of 3.5 parts of nitrogen, 0.82 parts became insoluble.

The numerous conflicting and contradictory results obtained in the chemical investigation of humus have undoubtedly resulted from different methods of preparation used. Robertson, Irvine and Dob-

1. Bul. No. 52, Bureau Soils, p. 21, U. S. Dept. of Agr. (1908).
2. Compt. Rend. Acad. Sci. Paris, 132 (1901 No. 7 pp. 435-437).
3. Jour. Chem. Soc. Lond. 1907, p. 686.
4. New Hamp. Ag. Expt. Sta. Bul. 138 (1908), p. 196.
5. Experiment Sta. Record, 13, p. 535 (1901-2).
6. Compt. Rend. Acad. Sci. (Paris) 141 (1905), p. 437.

son[1] found that the composition of natural humic acid, obtained from peat, varied greatly in composition, according to the method of preparation.

Van Schermbeck,[2] critically discussing the work of Malkomesius and Albert, considers that the so-called humus acids obtained by the latter, by repeated extraction with alcohol, are simply absorption-complexes, formed when colloids and resinous matter are precipitated by an electrolyte.

According to Suzuki[3] and Robinson,[4] nitrogen in humus is present as a kind of proteid and not as amino compounds; the amino acids as such being present only in traces and the latter compounds being only obtainable by treatment with hot hydrochloric acid.

Jodidi,[5] by the method of digestion with hydrochloric acid, found that the organic nitrogenous compounds in Iowa soils, and in the Michigan peat soils, are made up chiefly of acid amides and amino acids; and he concludes that it is "fairly safe to state that the bulk of the organic nitrogen in the majority of soils, if not all, consists very likely of acid amides and amino acids." These compounds, according to Suzuki, are the results of treatment with hydrochloric acid, and do not exist as such in the soil.

Humus has for some time ceased to be regarded as a definite chemical compound, or as composed of a few simple compounds. Of late, marked advance has been made in the separation and identification of the organic compounds entering into the composition of humus, or the so-called humic acids. Schreiner and Shorey[6] have isolated and described 20 organic compounds, representing 9 classes of chemical compounds. These compounds are the various degradation-products resulting from the decay of organic matter in the soil. Undoubtedly many other compounds will be discovered later.

It is now apparent that humus must be regarded as composed of numerous and more or less complex organic compounds, having distinct chemical and physical properties. The effects produced by humus must necessarily be complex and involved. Hence the simple methods now largely in use for the determination of humus are empirical in nature, and lack the accuracy of analytical methods depending upon the separation of a definite chemical compound. Some of

1. Bio-Chem. Jour. 2 (1907), No. 10 pp. 458-479.
2. Experiment Sta. Record 19 (1907-8), p. 622.
3. Bul. Col. Agr. Tokyo Imp. Univ. 7 (1907), No. 4, pp. 513-529.
4. Technical Bulletin No. 7, Mich. Ag. Col. Expt. Sta., p. 22 (1911).
5. Research Bul. No. 1, Iowa Ag. Expt. Sta., p. 46 (1911).
6. Bul. No. 74, Bureau of Soils, p. 45, U. S. Dept. Agr. (1910).

the properties of humus are to be attributed to its colloidal nature, as shown by Van Bemmelen; a field which it would appear has not been sufficiently investigated. Considerable difficulty must, then, be encountered in attempting to correlate the results of humus investigations with various systems of cropping.

II. EXPERIMENTAL

(a) Methods for Determination of Humus

Since the time of Grandeau, a large amount of labor has been devoted to the improvement and simplification of methods for the determination of humus, and to improving their accuracy. All these methods are based on the assumption that the humus is combined with the bases, lime and magnesia, which prevent it from passing into solution when treated with an alkali. The soil is accordingly first treated with dilute hydrochloric acid, to remove the bases, by leaching or shaking and filtering. After the removal of the acid by washing, the humus is extracted by leaching or shaking with alkali solution, and filtering to remove the humus extract. The points aimed at are: First, the complete removal of the bases, notably lime; second, the complete extraction of the humus, without admixture of clay, the accuracy of determination depending upon the obtaining of a solution of humus substances alone, dissolved in the alkali. The principal part of the work done in improving the methods has been devoted to securing the second object: i. e., preventing the admixture of clay, or the removal of it when already present. Hilgard[1] prevents the admixture with clay by leaching; but prolonged leaching is necessary for the complete removal of humus; rendering the method slow and wearisome. Methods devised by Huston and McBride,[2] and by Snyder,[3] for the purpose of shortening the time of extraction, by agitation in closed cylinders or flasks, necessarily result in bringing a large amount of clay into suspension; which, if not removed, gives high results. Frear,[4] and later Cameron and Breazeale,[5] removed the suspended mineral particles by use of a Pasteur filter; but the latter called attention to the possibility that some of the humus had been absorbed by the filter. Mooers and Hampton[6] endeavored to remove suspended clay by evaporating to dryness, on a steam bath, for purpose of deflocculating the clay and then extracting

1. Bul. 46, Purdue Univ. Ag. Expt. Sta. (1893), p. 69.
2. Bul. 46, Purdue Univ. Ag. Expt. Sta. (1893).
3. Jour. Amer. Chem. Soc., 16, p. 210 (1894).
4. Bul. 69, Bureau Chem., p. 40 (1902).
5. Jour. Amer. Chem. Soc. 26, p. 29 (1904).
6. Jour. Amer. Chem. Soc., 30, p. 805 (1908).

residue with 4 per cent ammonia, a procedure which unduly prolongs the method. Peter and Averitt[1] have proposed a correction-factor for the Huston and McBride or Official Method, which is of doubtful value. Methods for deflocculating and precipitating the suspended mineral matter have been devised by Stoddart,[2] and by Rather;[3] the former using ammonium sulphate and the latter ammonium carbonate as the precipitant. A centrifugal method has been devised by Wells, Stevenson and Coover,[4] which considerably reduces the time required for making the determination over that required by filtration methods.

(b) Errors in Humus Determinations.

All of the various methods devised for the determination of humus are subject to certain apparently unavoidable inaccuracies, due to the peculiar chemical and physico-chemical nature of humous substances, as previously discussed. Hence no method for the determination of humus can approach in absolute accuracy the results obtained in other analytical methods, which depend upon obtaining the substance in form of a compound of known composition and purity.

Rimbach[5] has shown that humus is lost on extraction with hydrochloric acid and water. In one case he found 300 c. c. of the filtrate to contain 0.0367 grams of organic matter with 7.45% of nitrogen; the organic matter being 4.53% of that contained in the ammonia extract.

Rimbach[6] determined the amount of combined ammonia taken up from the ammonia solution in the process of extracting the humus, and found this to be 4.93% of the ash-free ammonium humate. Emery[7] concluded from his work that ammonia was absorbed from the leaching-solution and entered into stable combination with the humus extract, thus giving high results. Emery also showed that undecomposed nitrogenous organic substances were soluble in dilute alkalies. He found that 27.3% of a sample of clover meal dissolved in a 5% solution of ammonia, by standing over night.

Reimbach[8] has shown that combined ammonia is a source of error in the determination of humic nitrogen. By making correction for the combined ammonia, he obtains the following results:

Organic nitrogen in 100 c.c. of ammonia sol. . . . 5.33 mg.
Organic nitrogen in 100 c.c. of soda sol. . . . . 8.23 mg.

1. Bul. No. 126 Ky. Ag. Expt. Sta. (1906), p. 122.
2. Jour. Ind. and Eng. Chem. 1 (1909), p. 72.
3. Jour. Ind. and Eng. Chem. 3 (1911), p. 660.
4. Bul. No. 124 Iowa Ag. Expt. Sta. (1911).
5. Jour. Amer. Chem. Soc. 22 (1900), p. 698.
6. Jour. Amer. Chem. Soc. 22 (1900), p. 695.
7. Jour. Amer. Chem. Soc. 22 (1900), p. 285.
8. Jour. Amer. Chem. Soc. 22 (1900), p. 698.

He concludes that his results prove that the soda solution extracts more nitrogen than does the ammonia, and that "The content of nitrogen of the soda extract being different from that of the ammonia extract, cannot be referred directly to the content of organic matter of the latter."

Emery[1] concludes that: "The determination of nitrogen in the caustic potash extract is always too low by the amount of nitrogen lost in the form of ammonia. Therefore, since the nitrogen in the caustic potash extract is too low, it follows that nitrogen in the humus would also be too low."

The above sources of error are deserving of more attention than they have heretofore received, and appear to warrant more careful investigation as to the limits of accuracy of the methods used.

(c) Errors Due to Presence of Clay.

In order to determine more accurately the effect of clay in the humus solution, determinations were made according to the official method for humus using kaolinite alone. From 5 to 6 grams of kaolinite were used for each determination. The ammoniacal extract was filtered through a Gooch, the filtration necessarily being very slow. A quite clear but somewhat opalescent solution was obtained which remained unchanged in appearance for a number of days. The following results were obtained:

	Loss on Ignition.	Ignited Residue.
Sample No. 1	0.40%	7.45%
Sample No. 2	0.33%	5.77%
Sample No. 3	0.47%	5.17%

On acidifying a portion of the solution with hydrochloric acid and adding barium chloride solution, a considerable precipitate was obtained. On acidifying another portion with hydrochloric acid and adding ammonium hydroxide, a small precipitate was obtained. Samples of kaolinite when dried at 100°C and then ignited gave the following results:

	Water.	Loss on Ignition.
Sample No. 1	0.09%	12.43%
Sample No. 2	0.08%	12.40%

It is concluded that the loss on ignition of the ammoniacal extract was principally due to the ammonia, which was not given off at 100°C, being combined or absorbed by the residue. It is also evident that a considerable portion of the clay passes into solution in the ammonium hydroxide; probably consisting to a considerable extent of soluble salts.

1. Jour. Amer. Chem. Soc. 22 (1900), p. 285.

(d) Relative and Absolute Accuracy of Methods.

As to the absolute accuracy of humus determination, unquestionably, the methods used fall considerably short of an approach to absolute accuracy. That this is necessarily so is evident from the physical and chemical properties of humus, as previously discussed, and from the resulting errors to which methods for its determination are subject. However, comparable results may have a very considerable value, though lacking to some degree in absolute accuracy. Provided all the determinations are made as nearly as possible under the same conditions, and with uniformity of procedure, the results obtained will enable us to follow the changes produced in soils by different systems of cropping, with a considerable degree of certainty.

In the following investigations, considerable care has been taken to obtain comparable results. The samples were all extracted the same length of time by solutions of the same strength; and attention was paid to uniformity of procedure in the other details of the work. As the soil-samples were taken from a soil of uniform character—a clay loam—and taken in a systematic manner (Minn. Bul. 109), it is believed that the results are fairly conclusive as to the changes which have taken place.

(e) Centrifugal and Official Methods Compared.

In course of various attempts to shorten the time required for the removal of suspended clay in the ammoniacal extract of humus, use was made of an electrically-driven centrifuge, which was run at a speed of 1395 revolutions per minute. At the end of 20 minutes it was found that all the clay which could be removed from the solution, in this manner, was precipitated. The following results were obtained by the centrifugal method, as compared with the Official method:

	Official Method		Centrifuge	
	Humus	Humus Ash	Humus	Humus Ash
Sample No. 1..........	1.56%	3.08%	1.63%	3.00%
Sample No. 2..........	1.47%	2.82%	1.47%	2.61%
Sample No. 3..........	1.63%	3.99%	1.60%	3.72%

By using the centrifuge, the time was considerably shortened. As is seen, the results are equally accurate, while the humus ash is a little lower. The centrifugal method was used in making the following determinations.

Nature of the Investigation.

The following determinations were made in order to find what changes had taken place in the humus and associated plant-food in certain plots of Field C, Minn. Agr. Exp. Sta., St. Paul, for the ten-year period from 1895 to 1905; also to find out what proportion of the total nitrogen, phosphoric acid and potash was associated with the humus, according to the methods used in this investigation. The samples used were collected as described in Bulletin No. 109, Minn. Exp. Station, and were the only samples available for the investigation.

Fertilizers Applied to Plots.

The plots have been fertilized as follows:

Series I, Plot 1, 8 tons of stable manure per acre once in 5 years applied to corn crop.

Series III, Plot 4, second crop of clover plowed under.

Series II, Plot 4, timothy top-dressed after mowing first hay crop.

Series IV, Plot 6, 8 tons of stable manure per acre once in 5 years applied to corn crop.

The plots are one-tenth acre each, being 2 rods by 8 rods. For additional details, see Bulletin No. 109, Minn. Exp. Station.

Results.

In the following table, the results are calculated on the basis of the moisture-free samples, heated to 102°C. Nitrogen is calculated as the element, and potassium and phosphorus are calculated as the oxide and anhydride, K_2O and P_2O_5 respectively.

(a) Table I—Changes in Humus Content of Soil

Series	Plot	Description of Rotations	Humus, Per Cent		
			1895	1905	Difference
II	7	Corn in hills continuously......	3.23	2.96	—0.27
II	9	Mangels continuously..........	3.03	2.85	—0.18
II	10	Field peas continuously........	2.87	3.28	+0.41
III	2	Wheat continuously, fall plow early......................	3.96	3.44	—0.52
III	4	Wheat, 1 yr.; clover, 1 yr.; plow under second crop...........	3.08	3.92	+0.84
I	1	Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr..	3.47	3.71	+0.24
II	2	Corn, 1 yr.; peas, 1 yr.; barley, 1 yr.; clover, 1 yr...........	4.33	4.63	+0.30
II	4	Barley, 1 yr.; oats, 1 yr.; timothy 2 yrs......................	3.78	4.31	+0.53
IV	6	Wheat, 1 yr.; clover and timothy, 2 yrs.; oats, 1 yr.; corn, 1 yr..	3.38	3.44	+0.06
IV	10	Wheat, 1 yr.; timothy and clover, 2 yrs.......................	3.18	2.79	—0.39

From an examination of the results given in Table I, it is seen that, in the case of the four plots cropped continuously, the greatest decrease in humus is in Series III, Plot 2; the decrease for the ten-year period being 0.52 per cent. The next greatest decrease is in the case of corn; while the plot cropped to mangels shows the least decrease; viz., 0.18%. Field peas give an increase of 0.41 per cent: being the only increase in humus in the continuously-cropped plots examined, and being doubtless due to the greater residue of organic matter left by the roots.

An increase in humus is found in every plot where rotation is practiced, except in case of Series IV, Plot 10, which shows a decrease of 0.39 per cent; but the decrease is 0.13 per cent less than in Series III, Plot 2, which was cropped to wheat continuously. The greatest increase in humus is found in Series III, Plot 4, a rotation with wheat and clover; the second crop of clover being plowed under. The next greatest increase is found in Series II, Plot 4, some considerable portion of the increase of 0.53 per cent being undoubtedly due to top-dressing the timothy. The least increase is found in Series IV, Plot 6, a five-year rotation including corn, the humus content remaining practically the same; while in Series I, Plot 1, is found an increase of 0.24 per cent. Both plots, it will be remembered, receive 8 tons of stable manure per acre once in five years. In Series II, Plot 2, where the rotation includes both peas and clover, the humus has increased 0.30 per cent. In general it is found that continuous cropping, except in case of field peas, decreases the amount of humus; and rotation of crops, on the whole, increases the amount of humus.

(b) Table II—Changes in Nitrogen Content

Field C		% Total Nitrogen			% Humus Nitrogen			% Humus Nitrogen, Calculated on basis of Soil		
Series	Plot	1895	1905	Difference	1895	1905	Difference	1895	1905	Difference
II	7	0.206	0.204	—0.002	3.37	2.89	—0.48	0.108	0.108	0.000
II	9	0.209	0.202	—0.007	3.62	3.32	—0.30	0.115	0.095	—0.020
II	10	0.186	0.268	+0.082	3.47	3.75	+0.28	0.099	0.123	+0.024
III	2	0.234	0.240	+0.006	3.28	3.59	+0.31	0.130	0.124	—0.006
III	4	0.206	0.293	+0.087	3.42	3.42	0.00	0.105	0.134	+0.029
I	1	0.235	0.270	+0.035	3.63	3.65	+0.02	0.126	0.135	+0.009
II	2	0.249	0.295	+0.046	3.18	3.39	+0.21	0.138	0.156	+0.018
II	4	0.217	0.271	+0.054	3.18	3.33	+0.15	0.120	0.143	+0.023
IV	6	0.216	0.207	—0.009	3.45	3.67	+0.22	0.116	0.126	+0.010
IV	10	0.215	0.206	—0.009	3.77	3.37	—0.40	0.120	0.094	—0.026

In comparing the determinations of total nitrogen given in Table II above with those given in Bulletin No. 109 (1908), this Station, Tables LIII, LIV, LV and LVI, differences will be noted in the results obtained on the same samples.

In general there is a fair agreement between results obtained on the 1895 samples; the principal differences are found in the results from the 1905 samples, the results reported in this investigation being in general considerably higher where the greatest differences occur. The determinations for this investigation were made according to the A. O. A. C. method[1] and were made in duplicate and in some cases in triplicate. Naturally the greatest differences would be expected in the older samples if changes had taken place in them. As the determinations reported in this investigation have been made with marked care in regard to calibration of apparatus and standardization of solutions, the differences are at present unexplainable.

On comparing the changes in total nitrogen, as shown in Table II in the continuously-cropped plots Series II, Plots 7, 9, 10, and Series III, Plot 2, it is seen that practically no change has taken place, except in Series II, Plot 10, where the increase of 0.082 per cent is due to the leguminous crop. In case of the plots where rotation is practiced, there is a marked increase in the amount of total nitrogen, except in Series IV, Plots 6 and 10, which show a slight decrease. As would be expected, the greatest increase in nitrogen is found in Series III, Plot 4, where the second crop of clover was plowed under. The next largest increase, of 0.054 per cent, is found in Series II, Plot 4, where the timothy is top-dressed after the first hay crop; but nearly as great an increase is found in Series II, Plot 2, in which both peas and clover are used in rotation.

The changes in humus-nitrogen are much more marked than in the case of total nitrogen. With continuous corn and mangels there is a decrease of nitrogen in the humus, the decrease being greater in the corn plot, Series II, Plot 7; but in the case of continuous wheat and continuous peas we have nearly the same increase. On examining the results from the rotation-plots, it is found that the nitrogen content of the humus shows no change in Series III, Plot 4, and Series I, Plot 1. In the other rotation plots there is an increase 0.15 to 0.22%, except in Series IV, Plot 10, which shows a decrease nearly equal to that of the continuous-corn plot; but, as was found, Series IV, Plot 10, shows a decrease of 0.39 per cent of humus. The effect of peas and clover is again seen in Series II, Plot 2, as compared with top-dressing the timothy in Series II, Plot 4, and the use of stable manure on Series I, Plot 1, and Series IV, Plot 6.

1. Bul. 107 (Revised) Bu. Chem., p. 19 (1910).

On calculating the humus nitrogen on the basis of the soil, the continuously-cropped plots show no change in the case of corn, a slight decrease in the case of wheat, and the greatest decrease in the case of mangels. The only increase in humus nitrogen from continuous cropping is found in the case of field peas. In all of the rotation plots except in Series IV, Plot 10, and Series III, Plot 4, there is an increase in humus nitrogen. The effect of plowing under the second crop of clover, and top-dressing the timothy, is plainly evident in Series III, Plot 4, and Series II, Plot 4.

In general, there is a fair agreement in regard to the direction of the changes in humus as compared with those of total nitrogen and humus nitrogen, as the result of different systems of cropping.

(c) Table III—Changes in Phosphoric Acid Content

Field C		% Total Phosphoric Acid			% Humus Phosphoric Acid			% Humus Phosphoric Acid Calculated on Basis of Soil		
Series	Plot	1895	1905	Differ-ence	1895	1905	Differ-ence	1895	1905	Differ-ence
II	7	0.124	0.146	+0.022	2.27	1.14	—1.13	0.073	0.033	—0.040
II	9	0.139	0.139	0.000	2.58	1.55	—1.03	0.077	0.044	—0.033
II	10	0.136	0.124	—0.012	2.81	1.64	—1.17	0.084	0.054	—0.030
III	2	0.200	0.169	—0.031	2.13	1.49	—0.64	0.084	0.051	—0.033
III	4	0.134	0.146	+0.012	2.45	0.83	—1.62	0.075	0.031	—0.044
I	1	0.151	0.162	+0.011	2.89	2.70	—0.19	0.100	0.100	0.000
II	2	0.181	0.179	—0.002	2.55	2.33	—0.22	0.110	0.108	—0.002
II	4	0.166	0.165	—0.001	2.73	2.46	—0.27	0.103	0.106	+0.003
IV	6	0.144	0.156	+0.012	3.13	2.77	—0.36	0.105	0.095	—0.010
IV	10	0.163	0.134	—0.029	2.85	3.15	+0.30	0.090	0.088	—0.002

From Table III it is seen that in the continuously-cropped plots the greatest deciease in total phosphoric acid (P_2O_5) is in the plots cropped to peas and to wheat, the latter having lost approximately one-seventh of its total phosphoric acid in ten years.

The increase in the corn plot, Series II, Plot 7, is apparently not explainable, unless due to errors in sampling, or possibly due to translocation from the sub-soil, changes in which have not been investigated as yet. It is also difficult to explain the increase in Series III, Plot 4, the analytical work having been carefully repeated. In the rotation plots, Series I, Plot 1, and Series IV, Plot 6, the effect of the application of stable manure is seen in increasing the total phosphoric acid content. Series II, Plot 2, and Series II, Plot 4, have practically the same amount of phosphoric acid at the end of the ten-year period as at the beginning, although the latter received a top-dressing.

Series IV, Plot 10, shows a decrease which was also found in case of humus, total nitrogen, and humus nitrogen.

The humus phosphoric acid has decreased in every plot except in Series IV, Plot 10. This decrease is very marked in all the plots continuously cropped, being least in case of the wheat plot. In the rotation plots the decrease is much less than in the plots continuously cropped, except in Series III, Plot 4, which shows an unusual decrease.

In the plots, Series I, Plot 1, and Series IV, Plot 6, which received an application of stable manure, the decrease is nearly twice as great in the latter plot; the greater depletion being possibly accounted for by being cropped to clover and timothy for two years.

When the humus phosphoric acid is calculated on the basis of soil, there is seen to be nearly the same decrease in humus phosphoric acid on all the continuously-cropped plots. In the rotation plots the amount of humus phosphoric acid, calculated on the basis of soil, is practically unchanged, except in case of Series III, Plot 4, and Series IV, Plot 6.

On the whole, there is no marked depletion of total phosphoric acid under systems of continuous cropping, except in the case of wheat. Generally for the ten-year period, the plots under a system of crop rotation have maintained the phosphoric acid content which they had at the beginning of the period. On the other hand, the humus of the plots continuously cropped has lost a large amount of phosphoric acid, and even under systems of crop rotation there is a loss.

(d) Table IV—Changes in Potash Content

Field C		% Total Potash			% Humus Potash			% Humus Potash Calculated on Basis of Soil		
Series	Plot	1895	1905	Difference	1895	1905	Difference	1895	1905	Difference
II	7	2.010	1.939	—0.071	1.64	0.81	—0.83	0.053	0.024	—0.029
II	9	1.815	1.910	+0.095	1.84	0.85	—0.99	0.056	0.024	—0.032
II	10	1.990	1.981	—0.009	2.09	0.96	—1.13	0.060	0.031	—0.029
III	2	1.897	1.710	—0.187	1.61	0.90	—0.71	0.064	0.031	—0.033
III	4	1.898	1.766	—0.132	1.39	0.46	—0.93	0.043	0.018	—0.025
I	1	1.817	1.848	+0.031	1.78	1.83	+0.05	0.062	0.068	+0.006
II	2	1.848	2.030	+0.182	1.66	1.49	—0.17	0.071	0.069	—0.002
II	4	2.154	2.030	—0.124	1.99	1.67	—0.32	0.075	0.072	—0.003
IV	6	1.882	1.807	—0.075	1.87	1.86	—0.01	0.063	0.064	+0.001
IV	10	1.949	1.863	—0.086	2.16	1.65	—0.51	0.068	0.046	—0.022

On comparing the changes in the amounts of total potash in the four continuously-cropped plots, as shown in Table IV, the greatest decrease is found in Series III, Plot 2, which is cropped to wheat. As was noted previously, this plot also showed the greatest loss in phosphoric acid. The variations in the results of total potash determinations are such that it is impossible to draw any general conclusions from them.

Comparing the results obtained for humus-potash, there is found to be a marked decrease in all the plots, except Series I, Plot 1, and Series IV, Plot 6; which, receiving 8 tons of stable manure once in five years, have practically the same amount as at the beginning of the ten-year period. On the whole there is a much greater decrease in humus-potash in the plots continuously cropped than in the rotation plots. The latter is also seen to hold true on comparing the results obtained by calculating the humus-potash on the basis of soil.

(e) Proportion of Plant Food Associated with Humus.

Cameron and Breazale,[1] in discussing the ash or mineral constituents of humus, "——— call attention to the considerable amounts of mineral matter dissolved in the ammoniacal extract, a large part of which is probably in organic combination." They conclude that: "this material is unquestionably in solution," as clear filtrates had been obtained by passing the solution through a Chamberland-Pasteur filter; also that the mineral material was largely in combination with the dissolved organic matter. Stoddart[2] treated apatite, wavelite, and dufrenite with 4% ammonia, and obtained results from which he concludes that "——— it is unsafe to determine phosphoric acid in the ammoniacal extract and call it humic phosphate." Stewart[3] concludes from the results of his investigation that: "The determination of the phosphorus associated with the precipitated *matiere noire* is not a quantitative method for the determination of the total organic phosphorus of the soil"; also, that "——— it would appear that the organic phosphorus associated with the precipitated *matiere noire* is only a very small part of the organic phosphorus present in the soil." Fraps[4] states that at present we have no method for determining the organic phosphoric acid of the soil.

1. Jour. Amer. Chem. Soc., 26, pp. 29-45 (1904).
2. Jour. Ind. and Eng. Chem. 1, p. 72 (1909).
3. Bul. No. 145. Univ. Ill. Ag. Expt. Sta. (1910), p. 121.
4. Texas Sta. Bul. No. 136, p. 33.

Table V—Percentage of Humus Nitrogen, Phosphoric Acid and Potash of Total Nitrogen, Phosphoric Acid and Potash of Soil

Field C		Nitrogen			Phosphoric Acid			Potash		
Series	Plot	1895	1905	Difference	1895	1905	Difference	1895	1905	Difference
II	7	52.4	52.8	+ 0.4	58.8	22.6	—36.2	26.3	12.3	—14.0
II	9	54.8	46.8	— 8.0	55.3	31.6	—23.7	30.8	12.5	—18.3
II	10	53.5	45.8	— 7.7	61.7	43.5	—18.2	30.1	15.6	—14.5
III	2	55.3	51.5	— 3.8	42.0	30.1	—11.9	33.7	18.1	—15.6
III	4	51.0	45.7	— 5.3	55.9	21.2	—34.7	22.6	10.1	—12.5
I	1	53.6	50.0	— 3.6	66.8	61.7	— 5.1	34.1	36.7	+ 2.6
II	2	55.4	52.8	— 2.6	60.7	60.3	— 0.4	38.4	33.9	— 4.5
II	4	55.2	52.7	— 2.5	62.4	64.2	+ 1.8	34.8	35.4	+ 0.6
IV	6	53.7	60.8	+ 7.1	72.9	60.8	—12.1	33.4	26.6	— 6.8
IV	10	55.8	45.6	—10.2	55.2	65.6	+10.4	34.8	24.6	—10.2

The results given in Table V are no doubt only approximate, especially with reference to the phosphoric acid and potash. As previously discussed, we have no means of knowing accurately what part of the nitrogen, phosphoric acid and potash are combined with the organic matter. Some portion of the phosphoric acid and potash is very likely extracted from the inorganic constituents of the soil: another portion is probably associated with the humus as a colloidal or absorption-complex; while the remaining portion is combined with organic matter.

Relatively, however, considering the accuracy of the methods used, the results given in Table V are of considerable interest, as showing the amounts of nitrogen, phosphoric acid and potash associated with the humus. Continuous cropping, on the whole, has brought about a marked reduction in the amount of phosphoric acid and potash associated with the humus, as compared with crop rotation.

SUMMARY AND CONCLUSION

Continuous cropping to corn, mangels and wheat causes a depletion of humus; on the other hand, field peas increase the amount of humus.

Generally, rotation of crops increases the amount of humus, the increase being greatest when clover is plowed under.

There is a fair agreement in regard to the direction of the changes in humus as compared with the changes in total nitrogen and humus-nitrogen; continuous cropping causing depletion, and rotation of crops an increase.

Except in the case of wheat, no marked decrease in total phosphoric acid has occurred in the continuously-cropped plots.

Generally, under systems of crop rotation, the plots have maintained the total phosphoric acid content for the ten-year period.

The humus-phosphoric acid has decreased in all the plots, with one exception, both under continuous cropping and systems of crop rotation; the depletion being greater in the continuously-cropped plots.

No definite conclusions can be drawn from the results obtained for total potash. However, a much greater depletion occurs in the case of wheat than in the other continuously-cropped plots.

In general, a marked decrease in humus-potash has occurred in the continuously-cropped plots, as compared with the rotation plots. In the rotation plots a decrease of humus-potash has occurred in all the plots, except those which received applications of stable manure.

The relatively large proportions of nitrogen, phosphoric acid and potash associated with the humus indicate the great importance and value of the latter as a source of plant-food.