THE AMOUNT OF HUMUS IN SOILS AND THE PERCENTAGE OF NITROGEN IN THE HUMUS, AS AFFECTED BY APPLICATIONS OF AIR-SLAKED LIME AND CERTAIN OTHER SUBSTANCES.

BY H. J. WHEELER, C. L. SARGENT, AND B. L. HARTWELL.

Received August 14, 1899.

IT is a well-known fact that lime, under favorable conditions, hastens the decomposition of organic matter. Notwithstanding this fact, however, lime is a most beneficial substance to apply to certain soils if used in rational quantities in connection with other manures, and provided such a system of manuring and cropping is employed that a sufficient supply of humus is maintained whether by the use of stable manure, muck, green manures, or by the occasional turning under of a grass sod.

In consideration of the interesting observations by Hilgard and Jaffa,[1] showing that the nitrogen content of the humus of certain soils of the arid regions of the United States exceeded in several instances eighteen per cent., and in view of the idea advanced later[2] by Hilgard to the effect that the nitrogen percentage of the humus may probably be taken as an indication of the degree of immediate assimilability of the nitrogen of soils, it seemed desirable to make a study of our own soil in its natural state and as affected by liming. The surface soil employed in this experiment came from plot OO of the cooperative acre located between fields B and C, and the subsoil was taken at the north end of the series of plots of which plot OO formed a part.[3] The surface soil and subsoil were each thoroughly mixed before being placed in the pots. The pots employed were galvanized iron ash-cans about twenty-six inches deep, and eighteen inches in diameter with bottoms inclined toward the center, at which point an opening was left to insure drainage. The pots were set into the soil to within two inches of the tops and agricultural drain tiles laid underneath, to prevent the ingress of surrounding soil-water. One hundred and fifty-four pounds of subsoil, and 100 pounds of surface soil were placed in each pot.

[1] *Agricultural Science*, 8, 165 (1894),

[2] Bulletin 47, U. S. Department of Agriculture, Division of Chemistry, pp. 58–60.

[3] See chart of experimental plots, Ninth Annual Report, Rhode Island Agricultural Experiment Station (1896).

The pots were filled in the spring of 1893. In 1893 and 1894 each manured pot received 7.36 grams of potassium chloride and 22.07 grams of dissolved bone-black. In the succeeding years, these amounts were increased to ten and twenty-five grams respectively. Wherever nitrogen was applied, it was at the rate of 2.65 grams per pot. Lime, unless otherwise specified, was applied in the form of air-slaked lime, practically free from magnesia, at the rate of 147.2 grams per pot (four tons per acre). Gypsum was applied so as to furnish the same amount of calcium oxide as the air-slaked lime at the rate of four tons per acre. Rhode Island capped corn (maize) was grown in the pots in 1893, oats in 1894, and spring rye in 1895. The soil employed in making the determinations was removed from the pots late in the autumn of 1895, or some weeks subsequent to the harvesting of the rye. In the case of pots which had been manured alike, approximately like amounts of soil were taken from each, and the samples for analysis were then taken from the mixture of these lots.

The following were the methods of analysis employed in the determination of humus and nitrogen in the humus: Humus was determined by first extracting the soil (twenty grams) with dilute hydrochloric acid as proposed by Hilgard,[1] but with the employment of an automatic washing apparatus, until no further reaction for lime was obtainable in the wash solution. The acid was then removed by successive washings with water until the wash-water was neutral.

In the subsequent treatment with ammonia, the Huston and McBride,[2] modification of the Grandeau method was employed. By this modification, the time of treatment and relation between volume of solvent and the quantity of material extracted, are constant factors. This seemed to be desirable in comparative tests, of the character under consideration. Successive extractions as proposed by Snyder[3] would undoubtedly have given even greater percentages of extract, since many extractions are necessary in the case of our upland soils to remove everything which can be dissolved by ammonia. It is not improbable, however, that a portion of the more insoluble extract may not be

[1] Wiley's Principles and Practice of Agricultural Analysis, Vol. I, p. 325.
[2] Wiley's Principles and Practice of Agricultural Analysis, Vol. I, pp. 327–328.
[3] Annual Report Minnesota Agricultural Experiment Station, 1893, pp. 251–252.

strictly humus, but may consist of unhumified matter extracted by the ammonia from plant residues.

The nitrogen in the humus was determined by using a two and one-half per cent. solution of potassium hydroxide in place of the solution of ammonium hydroxide of like strength, which was employed in the determination of humus. Aliquot portions of the extract were then neutralized with sulphuric acid, and after evaporating to dryness in a Kjeldahl flask, the nitrogen was determined as usual by the method of Kjeldahl. The soils were air-dried before analyzing, and the different samples contained from 2.00 to 2.75 per cent. of water, determined at 100° C. The following are the analytical results obtained, calculated to percentages of *dry* soil.

Nos. of pots.	Manures applied.[1]	Humous nitrogen in dry soil.	Humus in dry soil.	Nitrogen in dry humus.
21	Unmanured	0.130	3.86	3.37
16, 18, 25	Ammonium sulphate	0.128	3.93	3.26
15, 22	Ammonium sulphate, air-slaked lime (1 ton per acre)	0.133	3.77	3.53
17, 19, 26	Ammonium sulphate, air-slaked lime (4 tons per acre)	0.126	3.63	3.47
1, 8	Ammonium sulphate, calcium sulphate (land plaster) at a rate equivalent in CaO to 4 tons of air-slaked lime per acre	0.139	3.65	3.81
20, 27	Without nitrogen and lime	0.129	3.75	3.44
23, 24	Air-slaked lime (4 tons per acre)	0.139	3.51	3.68
6, 13	Sodium nitrate	0.143	3.93	3.64
7, 14	Sodium nitrate and air-slaked lime (4 tons per acre)	0.133	3.42	3.89

A study of the foregoing table reveals certain points of interest. Comparing the result from the pot which was unmanured (21), with that from those pots where potash and phosphoric acid were applied annually (20 and 27), it will be seen that the humus nitrogen and the percentage of humus had become but slightly less where the manures were applied, than in the unmanured soil, while the percentage of nitrogen in the dry humus showed also but slight variation.

[1] All of the pots except No. 21, received like amounts of potash and phosphoric acid.

By a comparison of the result where potash and phosphoric acid were employed (20 and 27), with that from the pots which received an additional application of lime (23 and 24), it appears that where lime was applied, the humus nitrogen in the soil had increased, and the percentage of humus had decreased 0.24 per cent., while the percentage of nitrogen in the humus had been augmented by 0.24 per cent.

In the case of the pots receiving nitrogen as sodium nitrate (6, 13, 7, and 14), it will be seen that the percentage of humus nitrogen was lower in the limed ones (7 and 14), and the humus was 0.51 of a per cent. lower but the percentage of nitrogen in the humus itself was 0.25 per cent. higher.

From an inspection of the results from the limed and unlimed ammonium sulphate pots (16, 18, 25, 15, 22, 17, 19, and 26), it will be seen that where lime was applied at the rate of one ton per acre (pots 15 and 22), the humus nitrogen was slightly greater, the humus was 0.16 per cent. less, and again the percentage of nitrogen in the humus itself was 0.27 per cent. greater.

In the case of the pots receiving lime at the rate of four tons per acre (pots 17, 19, and 26), no decided variation in the amount of humus nitrogen resulted, though the percentage of humus was found to be three-tenths per cent. less than where no lime was used, and, as in each of the other cases cited, the percentage of nitrogen in the humus was increased by liming.

Where calcium sulphate (gypsum or land plaster) was applied (pots 1 and 8), so as to furnish an amount of calcium oxide equivalent to that supplied by the air-slaked lime at the rate of four tons per acre, the humus nitrogen was 0.011 of a per cent. higher than where neither lime nor gypsum was applied (pots 16, 18, and 25), the humus was 0.28 of a per cent. lower, and the percentage of nitrogen in the humus 0.55 per cent. higher.

From the foregoing it will be seen that without exception the addition of air-slaked lime or gypsum resulted in lowering the total amount of humus, as compared with the unmanured plot, yet in every instance the percentage of nitrogen in the humus had been increased. In fact the latter statement applies also even where no nitrogen was added (pots 23 and 24).

Where lime was not applied, but nitrogen was employed in form of ammonium sulphate, which in the acid soil proved

poisonous to plants (pots 16, 18, and 25), it will be observed that the percentage of nitrogen in the humus was even less than where no manure was used (pot 21). On the contrary, where nitrogen in the form of sodium nitrate, was added without lime (pots 6 and 13), the percentage of nitrogen in the humus was greater than in the case of the unmanured soil (pot 21).

It is also of special interest to observe that in the case of the unlimed soil which received potash and phosphoric acid, but no nitrogen (pots 20 and 27), the percentage of humus became less than in the unmanured soil, while on the contrary, where nitrogen was applied as sodium nitrate, and as ammonium sulphate, to unlimed soil, it is possible that a slight increase in the percentage of humus resulted. The differences are not great enough, however, to furnish any positive evidence in this respect.

From what has preceded, in relation to the percentage of nitrogen in the humus, it seems probable, in case the view of Hilgard is correct, that the use of lime had actually increased the immediate assimilability of the humus nitrogen, notwithstanding the fact that the heaviest crops were produced by the limed pots. This is especially interesting in view of the fact that Hilgard and Jaffa[1] in twelve years' continuous cropping with grass upon soil of the California Station, found an increase of two-tenths per cent. in humus, but a decrease of nitrogen in the humus from eighteen to three per cent.

Lime has, as shown, decreased the percentage of humus, yet this has been in the case of continuous culture of cereals. In consideration, however, of the wonderful increase of roots and residual organic matter in our limed soils when they are seeded to grass, as compared with those which are unlimed, and since lime is well known to facilitate the humification of organic matter within the soil, there appears to be no danger of impoverishing the soil humus by the reasonable use of lime, wherever the land is occasionally left in grass for a few years, or where the supply of organic matter is maintained by the use of sufficient muck, stable manure, or by plowing in an occasional green crop. It is of considerable interest to note, where lime was applied, that notwithstanding the fact that the total humus was reduced, the percentage of nitrogen in the humus was increased in every case. However, this is in accord with the conditions which pre-

[1] Bulletin 47, U. S. Department of Agriculture, Division of Chemistry, 1895, p. 59.

vail generally where plant residues undergo decay. Hydrogen and oxygen are eliminated as water and carbon dioxide, more rapidly than nitrogen is eliminated.

Where sodium nitrate was applied without the use of lime, the percentage of humus nitrogen was greatest of all and the percentage of humus reached its maximum. The nitrogen in the humus was also two-tenths per cent. above that where nitrogen and lime were omitted (pots 20 and 27), and 0.27 per cent. above that where no manure was used (pot 21). This is particularly interesting in view of the fact that the unlimed sodium nitrate pots produced each season greater crops than pot 21, 20, or 27. These data indicate, therefore, a storage of some of the nitrate nitrogen within the soil in the form of organic matter,[1] which becomes quickly soluble in ammonium hydroxide, or, in other words, passes largely into a condition which permits of its classification with that organic complex which is termed humus.

In the light of recent investigations, it is probable that this may be accomplished by means of the denitrifying organisms which, while liberating some of the nitrogen in the gaseous state, may nevertheless store a portion in the soil in organic combinations. This view is also supported by the fact that lime decreases the activity of the denitrifying organisms, and that no such marked indications of the storage of nitrate nitrogen were observed where lime was employed. At all events, if these indications are verified by future investigations, it would seem probable that the disappearance of the nitrate nitrogen from a soil may not indicate the total loss of the nitrogen by cropping, drainage, and by elimination as gas, but that, under certain conditions, some portion of it at least may be transformed into a more stable form, which will subsequently become gradually available to plants.

It is to be regretted that opportunity has not been afforded to determine the total nitrogen content of the soils, together with the relative amounts of ammonium compounds, nitrates, and nitrites. It is hoped, however, that further time and means will become available in order that these interesting questions can be more extensively and thoroughly studied.

LABORATORY OF THE RHODE ISLAND
AGRICULTURAL EXPERIMENT STATION.

[1] Berthelot records a similar observation and concluded that it was due to purely chemical processes or to the activity of micro-organisms. *Compt. rend.*, 106, 638 (1888), abs. in *Chem. Centrbl.*, p. 486 (1888), cited from *Jsb. Agriculturchemie*, p. 22 (1888).