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The Chemical Nature of the Organic Nitrogen in the Soil

Influence of Various Factors on De- composition of Soil Organic Matter

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THE CHEMICAL NATURE OF THE ORGANIC NITROGEN IN THE SOIL

(Second Part—First Part appeared as Research Bulletin No. 1.)

By S. L. JODIDI.

INTRODUCTION.

It was shown in previous¹ publications that the acid-soluble organic nitrogen in Iowa soils as well as in Michigan peat soils is composed chiefly of acid amides, monamino acids and diamino acids. Following those publications, and also before, other papers appeared, dealing with the isolation of organic nitrogenous compounds from soils. Thus Schreiner and Shorey succeeded in isolating from various soils, in addition to a number of non-nitrogenous bodies, the diamino acids, arginine² and histidine, as well as the pyrimidine³ derivative, cystosine and the purine³ bases, xanthine and hypoxanthine. Prior to that Shorey extracted from Hawaiian soils a compound which he was able to identify as a pyridine derivative, picoline⁴ carboxylic acid, and which he was inclined to believe, existed in the form of a lime salt in the soil. Among the decomposition products of Michigan peat the two monamino acids, leucine⁵ and isoleucine, were isolated and identified by Robinson who also quantitatively determined the amino⁶ nitrogen in the peat by Van Slyke's⁷ nitrous acid method.

It is true that the above researches add materially to our knowledge concerning the nature of the organic compounds in soils, but the actual chemical nature of the organic matter will not be fully understood until all of its individual organic compounds have been discovered, isolated and identified, and the way they are linked together has been found out. That makes it desirable, if not imperative, to throw more light upon this paramount question. Especially is it important to know the character of the organic nitrogen in soils, for that is of fundamental value to agriculture, since it is intimately connected with the momentous biological processes of ammonification, nitrification and denitrification.

¹Jour. Am. Chem. Soc., **32**, 396 (1910); **33** 1226 (1911); Michigan Agr. Coll. Exp. Sta., Tech. Bul. 4 (1909); Iowa Agr. Exp. Sta., Research Bul. 1 (1911).

²Jour. Biol. Chem., **8**, 381, (1910).

³Ibid., **8**, 385 (1910); Bul. **74**, Bureau of Soils, U. S. Dept. Agr.

⁴Ann. Rept. of Hawaii Agr. Exp. Sta., 1906, p. 55.

⁵Jour. Am. Chem. Soc., **33**, 564 (1911).

⁶Mich. Agr. Exp. Sta., Tech. Bul. No. 7, p. 11.

⁷Berichte d. Deutsch. Chem. Ges., **43**, 3170 (1910).

It was for this reason that it was decided to investigate a number of soil plots as to the nature of the organic nitrogen in them.

The plots examined, S, T and V, formed a part of the Iowa Agricultural Experiment Station field which is situated on the Wisconsin Drift. The plots had an area of one-tenth of an acre each and were treated as follows:

In 1906 they received a heavy application of manure, in 1907, 1908 and 1909, none. They grew corn in 1905 and 1906, oats and clover in 1907, corn in 1908 and 1909.

The soil samples were taken in the fall of 1909 and represented composite samples of twenty-four borings taken from each plot to a depth of seven inches. On being air-dried they were passed through a half millimeter sieve.

While the percentage of moisture, ammonia and nitric acid was determined in both the air-dry and moist soil samples, all other determinations and observations reported in this bulletin were made with the air-dried soils only. The oven-dried soil, however, was taken as a basis for the calculation of all the tables given in this publication.

METHODS APPLIED IN THIS INVESTIGATION.

It was soon ascertained that the proportion of ammoniacal and nitric nitrogen in the plots under consideration was quite insignificant and attention was therefore directed towards the organic nitrogen.

The separation of the organic nitrogenous compounds into acid amides, diamino acids and monamino acids was performed according to the Hausmann-Osborne method, namely by distilling the evaporated acid extract of the soil with magnesia which gave in the form of ammonia all the nitrogen corresponding to the amides present in the soil. The residue on distillation of the soil extract with magnesia was thoroughly extracted with water and concentrated to 100cc. to which sulphuric acid and enough phosphotungstic acid was added to throw down the diamino acids present in the extract.

Ordinarily for every 0.15 gr. nitrogen contained in the soil extract five grams of sulphuric acid and thirty cc. of a solution containing five grams of sulphuric acid and twenty grams of phosphotungstic acid per 100cc. were applied. In all cases more of the phosphotungstic acid was added to the filtrate from the phosphotungstates to make sure that diamino acids were completely precipitated.

The Kjeldahlization of the washed phosphotungstic acid precipitate gave the amount of the diamino nitrogen. The per-

centage of the monamino nitrogen was obtained by subtracting the sum of ammoniacal, amido, and diamino nitrogen from 100.

The results secured by this method are recorded in Table I.

The data given in Table I need some explanation. In a former^s investigation it was demonstrated that with the Hausmann-Osborne method the ammonia obtained by distilling the evaporated extract of the soil with magnesia was actually pure ammonia which the acid amides split off, but that the phosphotungstic acid precipitate and the filtrate from that precipitate did not represent diamino and monamino acids only.

TABLE I.—AMOUNT OF NITROGEN IN THE VARIOUS COMPOUNDS.

Plot		Gram	Per cent. of oven dried soil	Percent of total soil Nitrogen	Percent of Nitro- gen in Solution
S	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.16069	0.1844	87.37	100.00
	Ammoniacal nitrogen	0.00081	0.0009	0.44	0.50
	Nitrogen of acid amides..	0.05397	0.0619	29.35	33.59
	Nitrogen of diamino acids.	0.02773	0.0318	15.08	17.26
	Nitrogen of monamino acids (difference from 100)	0.07818	0.0897	42.51	48.65
T	Total nitrogen in solution (obtained by boiling hydrochloric acid)	0.20247	0.2199	92.41	100.00
	Ammoniacal nitrogen	0.00099	0.0011	0.45	0.49
	Nitrogen of acid amides..	0.06789	0.0737	30.99	33.53
	Nitrogen of diamino acids.	0.04029	0.0438	18.39	19.90
	Nitrogen of monamino acids (difference from 100)	0.09330	0.1013	42.58	46.08
V	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.12675	0.2216	88.98	100.00
	Ammoniacal nitrogen	0.00062	0.0011	0.43	0.49
	Nitrogen of acid amides..	0.04207	0.0735	29.53	33.19
	Nitrogen of diamino acids	0.01797	0.0314	12.61	14.18
	Nitrogen of monamino acids (difference from 100)	0.06609	0.1155	46.40	52.14

To find out just how much of the diamino and monamino nitrogen given in Table I actually belonged to diamino and mon-

^sJour. Am. Chem. Soc., 33, 1241 (1911).

amino acids, the solutions in question were subjected to analysis by the formol-titration⁹ method.

DETAILS OF THE FORMALDEHYDE TITRATION METHOD.

A few cautions may not be amiss in connection with the use of this method. In order to avoid mistakes it is necessary to use for titration enough of the amino acids: the more of them employed for the formol-titration, the more accurate are the results. Further, it is of advantage to start the formol-titration of the soil extract supposed to contain amino acids, not in the alkaline, but in the acid state; i. e., the soil extract to be formol-titrated is slightly acidified with hydrochloric acid so as to require, say, from one to three cc. of $\frac{n}{5}$ barium hydroxide. With these precautions and under observation of conditions outlined elsewhere,¹⁰ the formaldehyde titration method gives accurate quantitative results practically for all monamino acids. This is also true of the diamino acids in case one of them only is contained in the sample to be titrated. If several diamino acids are present, then the calculation of the formol-titrimetrical results is more complicated.

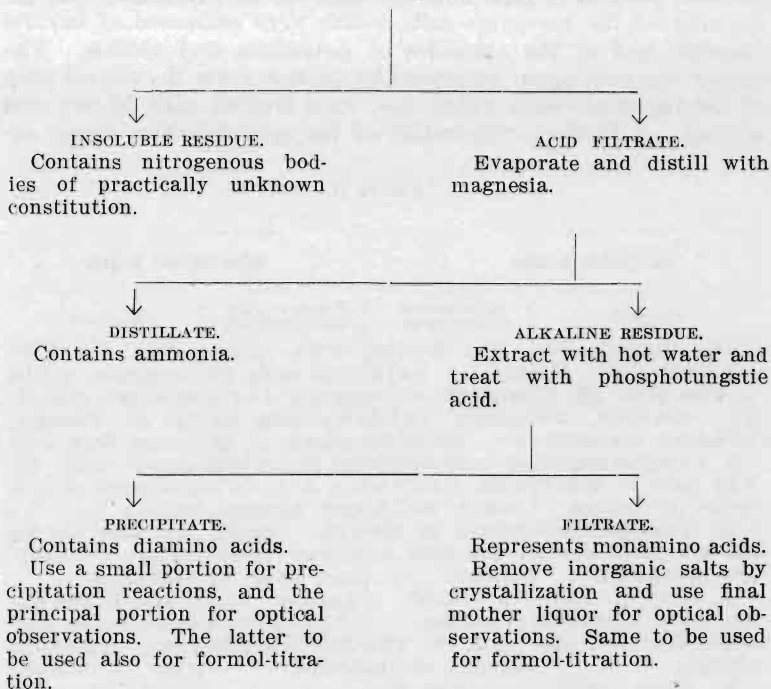
The operations in question are conveniently carried out as follows: The soil extract containing amino acids, upon examination of the optical activity in the polariscope, is made up to a definite volume, say, to 60cc. of which 15cc. are Kjeldahlized to ascertain the total nitrogen present in the sample, 15cc. are titrated in the ordinary way to determine the percentage of acidity of the substance, and two portions of 15cc. each are formol-titrated to find the increase of acidity due to the reaction with neutralized formaldehyde. These three operations furnish all the data necessary for the calculation of the percentage of diamino or monamino acids present in the substance under examination.

For the sake of convenience the method of separation of the organic nitrogenous compounds into the various groups is schematically presented as follows:

⁹Bioch. Zeitschr. **7**, 45 (1907); **7**, 407 (1908; Zeitschr. physiol. Chem. **60**, (1909); **64**, 121 (1910).

¹⁰Research Bul. 1, Iowa Agr. Expt. Sta., page 35, etc.

Digest soil with boiling hydrochloric acid.



In connection with the scheme just given it should be borne in mind that the distillate obtained by distilling the evaporated acid filtrate with magnesia contains the ammonia originally present as such in the soil, as well as the ammonia split off from the acid amides by boiling with acid. Further, the precipitate containing diamino acids and the filtrate representing monamino acids are freed from phosphotungstic acid by means of barium hydroxide the excess of which is removed with CO_2 . The filtrate from barium carbonate is then treated as given in the scheme. Both the precipitate and filtrate may contain also nitrogenous compounds other than diamino and monamino acids.

SEPARATION OF THE MONAMINO ACIDS FROM INORGANIC SALTS.

The monamino acids present in the extracts from the various soil samples investigated were separated from the inorganic salts by crystallization. Usually the mother liquor was filtered off with suction from the first crop of crystals which consisted mainly of barium chloride. They were washed with 96 per cent alco-

hol. The separated mother liquor, on being mixed with the wash alcohol, yielded within half an hour or so practically the remainder of the inorganic salts which were composed of barium chloride and of the chlorides of potassium and sodium. The liquor was now again separated by suction from the second crop of the inorganic salts which, too, were treated with 96 per cent alcohol. A further evaporation of the second mother liquor or-

TABLE II.

DIAMINO ACIDS		MONAMINO ACIDS	
Reactions	Polariscopic Examination	Reaction with Formaldehyde	Rotation
<p>The diamino acids extracted from the various plots (S, T, V), displayed the following reactions:</p> <ol style="list-style-type: none"> 1. Phosphotungstic acid gave a heavy, white precipitate. 2. Phosphomolybdic acid gave a yellow precipitate. 3. Mercuric chloride gave a grayish white flocculent precipitate. 4. Silver nitrate gave a grayish or yellowish white precipitate, soluble in excess of ammonia. 5. Picric acid either failed to give a precipitate or the precipitate obtained after some time was quite insignificant. 6. The aqueous solution of the diamino acids was strongly alkaline. 7. Addition of neutralized formaldehyde to the alkaline solution caused it to turn acid pointing to the presence of carboxyl and amino groups. 	<p>Plot S. The diamino acid solution containing 0.006 gr. nitrogen, on acidulating with hydrochloric acid, rotated in the 2 dm. tube as follows: $\alpha = +0.09^\circ$. (Ventzke).</p> <p>Plot T. The rotation of the acidulated diamino acid solution, with 0.008 gr. nitrogen was $\alpha = +0.22^\circ$.</p> <p>Plot V. The diamino acid solution, with 0.007 gr. nitrogen, having been strongly acidulated with hydrochloric acid, showed the rotation of $\alpha = +0.20^\circ$.</p>	<p>The monamino acids extracted from the soils examined, on being mixed with neutralized formaldehyde, immediately turned acid, thus indicating the presence of COOH and NH₂ groups.</p>	<p>Plot S. The monamino acid solution, with 0.042 gr. nitrogen, having been acidulated with hydrochloric acid, showed in the 2 dm tube the rotation $\alpha = +0.61^\circ$ (Ventzke).</p> <p>Plot T. The monamino acid solution containing 0.040 gr. nitrogen rotated as follows: $\alpha = -0.75^\circ$. When acidulated with 5 cc conc. hydrochloric acid, the same solution showed the rotation $\alpha = +0.1^\circ$.</p> <p>Plot V. The aqueous solution of the monamino acids, extracted from about 150 grams soil, showed the rotation $\alpha = -0.73^\circ$. Acidulated with 3 cc conc. hydrochloric acid, the same solution showed the rotation $\alpha = +0.5^\circ$.</p>

dinarily furnished but an insignificant amount of inorganic salts which were treated in the above manner. The final mother liquors of the various soils obtained in the manner described contained practically nothing but organic compounds. They showed acid reaction immediately upon the addition of neutralized formaldehyde, hence they contained the NH_2 and COOH group. They showed optical activity, consequently they contained an asymmetric C-atom and had the NH_2 group very likely in the α position.

In Table II are presented the facts which go to show that the substances designated in Table I as diamino and monamino acids actually display reactions and possess properties which are characteristic of those compounds.

The determinations of the rotatory power of the soil extracts as presented in Table II have but a qualitative value. No effort was made to determine the specific rotatory power because of the probable presence of several amino acids in each of the soil extracts examined. We had in view only the object to find out whether the solutions, supposed to contain diamino or monamino acids, were optically active or inactive.

As shown in another investigation,¹¹ not all of the nitrogen obtained by the Hausmann-Osborne method as nitrogen of diamino and monamino acids actually represents diamino and monamino nitrogen, but a portion of that nitrogen belongs to classes other than amino acids. To find out just what proportion of that nitrogen is really made up of diamino and monamino acids, the soil extracts from the plots, S, T, V were subjected to formaldehyde titration with the results given in Table III.

TABLE III.

Plot	DIAMINO ACIDS.	MONAMINO ACIDS.
S.	The soil extract containing diamino acids was made up to 60cc. of which 15cc. were titrated in the usual way and required 0.2cc. $\frac{1}{5}$ barium hydroxide, and two portions of 15cc. each were formol-titrated and required on the average 0.6cc. $\frac{1}{5}$ barium hydroxide. This means that the increase of the acidity caused by the presence of diamino acids is corresponding to 0.4cc. $\frac{1}{5}$ barium hydroxide. Unfortunately, 15cc. of the soil extract oxidized according to Kjeldahl were lost so that the actual percentage of the diamino acids could not be calculated.	Sixty cc. of the soil extract containing monamino acids were treated as follows: 15cc. were Kjeldahlized and the ammonia obtained required 10.02cc. $\frac{1}{10}$ H_2SO_4 corresponding to 0.01407 gram nitrogen; 15cc. were titrated and required 2.2cc. $\frac{1}{5}$ barium hydroxide; two portions of 15cc. each were formol-titrated and required on the average 5.61cc. $\frac{1}{5}$ barium hydroxide. This means that 3.41cc. $\frac{1}{5}$ barium hydroxide equivalent to 0.00957 gr. nitrogen, or 68.02 per cent of what is given in Table I as nitrogen of monamino acids actually represent monamino nitrogen. The other 31.98 per cent belong to classes other than monamino acids.

¹¹Jour. Am. Chem. Soc., 33, 1239 (1911).

TABLE III (Continued)

Plot	DIAMINO ACIDS.	MONAMINO ACIDS.
T.	<p>The soil extract containing diamino acids was made up to 60cc. The Kjeldahlization of 15cc. showed that they contain 0.006 gr. nitrogen; 15cc. titrated in the ordinary way required 1.47cc. $\frac{1}{5}$ barium hydroxide; two portions of 15cc. each formol-titrated required 2.04cc. $\frac{1}{5}$ barium hydroxide. This means that the 60cc. substance through formaldehyde increased in acidity the amount of which is equivalent to 2.28cc. $\frac{1}{5}$ barium hydroxide or 1.01280 gr. nitrogen (53.3%) of lysine alone were present, or 0.01921 gr. nitrogen (80.0%), if histidine alone were present; or 0.02561 gr. nitrogen (106.7%), if arginine only were present. While these figures do not give the actual percentage of each one of the diamino acids, they do show that the total percentage of the diamino acids is quite considerable. In other words, a large portion of what is given in Table I as nitrogen of diamino acids actually represents diamino nitrogen.</p>	<p>The formol-titration of 60cc. substance, with 0.05520 gr. nitrogen, showed that 82.03% of what is given in Table I as nitrogen of monamino acids, actually represents monamino nitrogen, the rest consisting of nitrogenous compounds other than monamino acids.</p>
V.	<p>Sixty cc. of the soil extract were analyzed with this result:</p> <p>The titration of 15cc. of this solution required 2.35cc. $\frac{1}{5}$ barium hydroxide; the formol-titration of two portions of 15cc. each required on the average 3.02cc. $\frac{1}{5}$ barium hydroxide. Hence, the increase of acidity through formaldehyde is equal to 0.67cc. $\frac{1}{5}$ barium hydroxide. The Kjeldahl determination of 15cc. of this solution was unfortunately lost by accident, which rendered the calculation of the actual percentage of diamino nitrogen impossible.</p>	<p>The substance containing monamino acids was analyzed with the following result:</p> <p>15cc. were Kjeldahlized and found to contain 0.0097 gr. nitrogen.</p> <p>15cc. titrated in the ordinary way required 3.55cc. $\frac{1}{5}$ barium hydroxide; two portions of 15cc. formol-titrated required on the average 6.52cc. $\frac{1}{5}$ barium hydroxide. This means that the increase of acidity due to the reaction with formaldehyde was equivalent to 2.97cc. $\frac{1}{5}$ barium hydroxide = 0.00834 gr. nitrogen. Or $0.00834 \times \frac{100}{0.00970} = 85.98$ per cent of what is recorded in Table I as nitrogen of monamino acids actually represent monamino nitrogen.</p>

While the data before us to a certain degree modify the results reported in previous publications, especially as far as the percentage of diamino and monamino acids is concerned, yet this modification does not go far enough to shift the ratio of the acid amides to the diamino and monamino acids. Here, as in our

earlier investigations, the percentage of monamino acids is predominant; next in proportion follow the acid amides, and finally the diamino acids. The percentage of the ammoniacal nitrogen is insignificant.

In comparing the results, it is to be borne in mind that whereas in laboratory or pot experiments it is easy to get good average samples, it is quite different with field or plot experiments. In the first place it is not an easy task to obtain one or several tons of manure, hay or straw as a uniform and homogeneous mass. Nor is it possible to distribute such organic materials absolutely evenly throughout the plots. Likewise, it is very difficult, if at all possible, to get a truly average soil sample from a plot of the size of one-tenth of an acre. It is for these reasons that samples from the same plot, and still more from different plots, though treated with the same organic materials, may in some measure differ from each other. This may account for some differences in the results reported, yet on the whole the data secured in the above experiments confirm the results reported in the former¹² publications.

CONCLUSIONS.

The data at hand permit of the following conclusions:¹³

1. The principal portion of the acid-soluble organic nitrogen contained in the soils herein investigated is made up of acid amides, monamino acids and diamino acids.

2. The larger part of the phosphotungstic acid precipitate obtained by the Hausmann-Osborne method in the manner described in this publication and recorded in Table I as nitrogen of diamino acids, actually represents diamino nitrogen, the smaller part belonging to classes other than diamino acids.

3. In the case of the filtrate from the phosphotungstic acid precipitate presented in Table I as nitrogen of monamino acids, it was found that from 68.02 to 85.98 per cent of that filtrate in fact represented monamino nitrogen, the remainder, from 31.98 to 14.02 per cent, consisting of nitrogenous compounds other than monamino acids. The above conclusions refer to that portion of the organic nitrogen which could be extracted by boiling with hydrochloric acid.

¹²loc. cit.

¹³In conclusion 10, on p. 46 of Research Bul. 1, Iowa Agr. Expt. Sta., the word "acid-soluble" was omitted by the printers. It should correctly read as follows: "Since we have found that the acid-soluble organic nitrogenous compounds in Iowa soils as well as in Michigan peat soils are made up chiefly of acid amides and amino acids, despite a considerable variety of the sources of the organic nitrogen, it seems fairly safe to state that the bulk of the acid-soluble organic nitrogen in the majority of soils, if not in all, consists very likely of acid amides and amino acids."

THE CHEMICAL NATURE OF THE ORGANIC NITROGEN IN THE SOIL

(Third Part.)

By S. L. JODIDI and A. A. WELLS.

The fact that soil organic matter is the result of decomposed or still decaying vegetable and animal tissues, not infrequently of very different nature, prompted an examination of a considerable number of plots treated with different organic materials under a variety of conditions. The plots chosen for this investigation formed part of the experiment station field which is located on the Wisconsin Drift. The plots, A, B, C, D, F, G, I, K, L, M, R, S, T and V, one-tenth of an acre each and the plots O, P, had an area of one-twentieth of an acre each and the plots Q, P, R, S, T and V, one-tenth of an acre each. Their treatment can best be seen from the following tabulation:

TREATMENT PER ACRE

Plot		1907.	1908.	1909.
A	.....	No Treatment....	No Treatment....	No Treatment....
B	.....	Two tons of Peat.	Two tons of Peat.	Two tons of Peat.
C	.....	No Treatment....	No Treatment....	No Treatment....
D	.....	No Treatment....	No Treatment....	No Treatment....
F	.....	Two tons of Tim- othy	Two tons of Tim- othy	Two tons of Tim- othy
G	.....	No Treatment....	No Treatment....	No Treatment....
I	.....	One ton of Clover Hay	One ton of Clover Hay	One ton of Clover Hay
K	.....	Four tons of Clo- ver Hay	Four tons of Clo- ver Hay	Four tons of Clo- ver Hay
L	.....	One ton of Ma- nure	One ton of Ma- nure	One ton of Ma- nure
M	.....	Two tons of Ma- nure	Two tons of Ma- nure	Two tons of Ma- nure
O	.....	No Treatment....	No Treatment....	No Treatment....
P	.....	No Treatment....	No Treatment....	No Treatment....
R	.....	No Treatment....	No Treatment....	No Treatment....
S	.....	No Treatment....	No Treatment....	No Treatment....
T	.....	No Treatment....	No Treatment....	No Treatment....
V	.....	No Treatment....	No Treatment....	No Treatment....

All plots received a heavy application of manure in 1906

PREVIOUS CROPPING

Plot	1903	1904	1905	1906	1907	1908	1909
A	Corn	Oats	Corn	Corn	Oats	Timothy	Timothy
B	"	"	"	"	"	Fallowed	Fallowed
C	"	"	"	"	"	"	"
D	"	"	"	"	"	"	"
F	"	"	"	"	"	"	"
G	"	"	"	"	"	"	"
I	"	"	"	"	"	"	"
K	"	"	"	"	"	"	"
L	"	"	"	"	"	"	"
M	"	"	"	"	"	"	"
O	"	"	"	"	Corn	Corn	Corn
P	"	"	"	"	Corn	"	Oats
R	"	"	"	"	Oats & Clover	"	Corn
S	"	"	"	"	"	"	"
T	"	"	"	"	"	"	"
V	"	"	"	"	"	"	"

Each of the soil samples examined represents a composite of twelve or twenty-four borings taken from each plot to the depth of seven inches. For analytical purposes the samples were air dried, ground in a ball mill and finally passed through a sieve having 400 perforations to the square inch. The amount of soil which did not pass through the sieve was negligible. For the sake of convenience the analytical data are given in the form of tables.

TABLE I

PLOT	Wet soil used	Water Found			Air dry soil used	Water Found		
		Grams	Gram	Percent		Average	Grams	Gram	Percent	Average
A	2.5307	0.4030	15.92	16.00	3.0022	0.1699	5.66	5.63
	2.8626	0.4604	16.08		3.0001	0.1682	5.61	
B	3.7181	0.7281	19.58	18.64	2.9996	0.1533	5.11	5.11
	2.4747	0.4382	17.70		3.0016	0.1535	5.11	
C	3.0209	0.5981	19.80	19.28	3.0014	0.1575	5.25	5.24
	3.7587	0.7050	19.76		3.0013	0.1566	5.22	
D	3.2467	0.5662	17.44	17.70	3.0008	0.1414	4.71	4.76
	2.6739	0.4804	17.97		3.0008	0.1445	4.81	
F	2.3785	0.3777	15.88	16.08	3.0002	0.1272	4.24	4.24
	1.9364	0.3155	16.29		3.0012	0.1274	4.24	
G	2.5472	0.3907	15.34	15.38	3.0019	0.1160	3.86	3.87
	3.2802	0.5062	15.43		3.0004	0.1164	3.88	
I	2.3000	0.3324	14.45	14.30	3.0024	0.0904	3.01	3.03
	2.6390	0.3737	14.16		3.0015	0.0914	3.04	
K	3.1478	0.4559	14.48	14.69	3.0027	0.0867	2.89	2.86
	3.1799	0.4736	14.89		3.0041	0.0855	2.84	
L	3.9063	0.6162	15.77	15.74	3.0000	0.0963	3.21	3.18
	3.3418	0.5252	15.72		3.0008	0.0946	3.15	
M	1.8502	0.3072	16.60	16.51	3.0008	0.0975	3.25	3.24
	2.6021	0.4273	16.42		3.0007	0.0971	3.23	
O	2.5619	0.2964	11.57	11.62	3.0035	0.0917	3.05	3.11
	2.9751	0.3471	11.67		3.0016	0.0955	3.18	
P	3.2655	0.5725	17.53	17.33	3.0008	0.1063	3.54	3.51
	3.0391	0.5207	17.13		3.0012	0.1048	3.49	
R	2.9275	0.3729	12.74	12.83	3.0000	0.0933	3.11	3.13
	3.4204	0.4422	12.93		3.0009	0.0947	3.15	
S	2.5441	0.2988	11.74	11.81	3.0008	0.0849	2.83	2.81
	2.6336	0.3130	11.88		3.0014	0.0837	2.79	
T	2.6343	0.3484	13.23	13.22	3.0000	0.1044	3.48	3.53
	3.0655	0.4052	13.22		3.0002	0.1076	3.58	
V	1.9543	0.2099	10.74	10.73	3.0000	0.1078	3.59	3.60
	1.9605	0.2099	10.71		3.0008	0.1083	3.61	

With the exception of A and P, all the plots which grew crops in 1909, when the soil samples were taken, individually show a lower percentage of moisture than the fallowed plots. On the average the soils of the fallowed plots had about three per cent more moisture than those of the cropped plots. This confirms the observations already reported in the first paper of this series,¹ that fallowing is one of the means for the accumulation of moisture in the soil.

The estimation of the specific gravity as well as of the total nitrogen in the various plots will be found in the table following.

¹Iowa Agr. Expt. Sta., Research Bul. 1, p. 11.

TABLE II.

Plot	Specific Grav- ity	Average	Total Nitrogen per cent	Average
A	2.387	2.476	0.397	0.400
	2.564		0.403	
B	2.481	2.510	0.355	0.372
	2.539		0.389	
C	2.432	2.414	0.369	0.364
	2.395		0.360	
D	2.584	2.583	0.318	0.319
	2.582		0.320	
F	2.597	2.598	0.274	0.268
	2.600		0.262	
G	2.594	2.596	0.248	0.246
	2.598		0.244	
I	2.592	2.599	0.210	0.214
	2.607		0.219	
K	2.601	2.602	0.220	0.222
	2.603		0.225	
L	2.422	2.510	0.236	0.231
	2.599		0.225	
M	2.585	2.586	0.218	0.221
	2.587		0.223	
O	2.609	2.608	0.220	0.215
	2.606		0.209	
P	2.604	2.604	0.215	0.218
	2.604		0.220	
R	2.610	2.537	0.220	0.217
	2.464		0.213	
S	2.611	2.612	0.211	0.211
	2.614		0.211	
T	2.586	2.588	0.236	0.238
	2.591		0.240	
V	2.599	2.599	0.253	0.249
	2.599		0.245	

The knowledge of the specific gravity of the soils allows us with reasonable accuracy to estimate the nitrogen in the soil extracts by simply making them up to a definite volume and Kjeldahlizing an aliquot of it, which is then recalculated to the total volume of the liquid.

The ammoniacal and nitric nitrogen was determined, as was also the moisture of the soils, in both the wet and air-dry samples. While the percentages of ammoniacal and nitric nitrogen make it possible to find the proportion of the organic nitrogen by subtracting their sum from the total soil nitrogen, they are of further interest in that they represent the immediately available nitrogenous plant food and show at the same time what is going on in the plots in the way of ammonification and nitrification. The data in question are recorded in Tables III, IV, V and VI.

TABLE III.

AMMONIACAL NITROGEN IN THE WET SOIL SAMPLES OF THE VARIOUS PLOTS.

Plot	Wet soil used Grams	Ammoniacal Nitrogen found			Per cent of total soil Nitrogen	Average
		Gram	Per cent of oven-dry soil	Average		
A	50.0	0.0003510	0.000836	0.000668	0.209
		50.0	0.0002106	0.000501		0.125
B	50.0	0.0004914	0.001208	0.001035	0.323
		50.0	0.0003510	0.000863		0.231
C	50.0	0.0003510	0.000870	0.000370	0.239
		50.0	0.0003510	0.000870		0.239
D	50.0	0.0002106	0.000512	0.000512	0.160
		50.0	0.0002106	0.000512		0.160
F	50.0	0.0002106	0.000502	0.000502	0.187
		50.0	0.0002106	0.000502		0.187
G	50.0	0.0002808	0.000663	0.000663	0.270
		50.0	0.0002808	0.000663		0.270
I	50.0	0.0000702	0.000164	0.000328	0.077
		50.0	0.0002106	0.000492		0.230
K	50.0	0.0002808	0.000658	0.000576	0.296
		50.0	0.0002106	0.000494		0.222
L	50.0	0.0006318	0.001500	0.001333	0.649
		50.0	0.0004914	0.001167		0.505
M	50.0	0.0000702	0.000168	0.000168	0.076
		50.0	0.0000702	0.000168		0.076
O	50.0	0.0000702	0.000159	0.000238	0.074
		50.0	0.0001404	0.000318		0.148
P	50.0	0.0002106	0.000509	0.000509	0.234
		50.0	0.0002106	0.000509		0.234
R	50.0	0.0002106	0.000483	0.000483	0.223
		50.0	0.0002106	0.000483		0.223
S	50.0	0.0002808	0.000637	0.000477	0.302
		50.0	0.0001404	0.000318		0.151
T	50.0	0.0002808	0.000647	0.000566	0.272
		50.0	0.0002106	0.000485		0.204
V	50.0	0.0004212	0.000944	0.000944	0.379

As can be seen from the figures just presented, the amount of ammoniacal nitrogen which was estimated by distillation with magnesia is very small throughout all the plots. This is also true of the air-dry soil samples recorded in Table IV.

While the percentage of ammoniacal nitrogen in both the wet and air-dry soil samples is on the whole insignificant, a closer examination of the figures contained in Tables III and IV shows that, without a single exception, the ammonia in the wet soils is somewhat lower than in the corresponding air-dry soils. This is at first sight striking when we take into consideration that both tables were calculated to the same (dry) basis and that the wet as well as the air-dry soils represent identical samples, with the

TABLE IV.

AMMONIACAL NITROGEN IN THE AIR-DRY SOIL SAMPLES OF THE VARIOUS PLOTS.

Plot		air-dry soil used Grams	Ammoniacal Nitrogen Found				Average
			Gram	Per cent of oven-dry soil	Average	Per cent of total soil Nitrogen	
D	....	50.0	0.0003791	0.000796	0.000649	0.249	0.203
		50.0	0.0002387	0.000501		0.158	
F	....	50.0	0.0003791	0.000792	0.000792	0.296	0.296
		50.0	0.0003791	0.000792		0.296	
G	.....	50.0	0.0005195	0.001081	0.001227	0.439	0.498
		50.0	0.0006599	0.001373		0.558	
I	....	50.0	0.0005195	0.001072	0.001072	0.501	0.501
		50.0	0.0005195	0.001072		0.501	
K	....	50.0	0.0005195	0.001070	0.001070	0.482	0.482
		50.0	0.0005195	0.001070		0.482	
L	....	50.0	0.0008003	0.001653	0.001508	0.716	0.653
		50.0	0.0006599	0.001363		0.590	
M	.....	50.0	0.0003791	0.000783	0.000856	0.354	0.387
		50.0	0.0004493	0.000929		0.420	
O	....	50.0	0.0003791	0.000782	0.000782	0.364	0.364
		50.0	0.0003791	0.000782		0.364	
P	.....	50.0	0.0005195	0.001077	0.001077	0.494	0.494
		50.0	0.0005195	0.001077		0.494	
R	....	50.0	0.0003791	0.000783	0.000783	0.361	0.361
		50.0	0.0003791	0.000783		0.361	
S	....	50.0	0.0005195	0.001069	0.000924	0.507	0.438
		50.0	0.0003791	0.000780		0.370	
T	....	50.0	0.0005195	0.001077	0.001077	0.453	0.453
		50.0	0.0005195	0.001077		0.453	
V	.....	50.0	0.0005195	0.001078	0.001078	0.433	0.433
		50.0	0.0005195	0.001078		0.433	

difference, of course, that the samples recorded in Table IV were air dried prior to estimating the ammonia in them, and with the further difference that the ammonia determinations of the air-dry soils were made first. The estimation of ammonia in the wet soils was carried out after they had been allowed to remain in sealed jars for about one year. This accounts for the differences noticed, as there can be no doubt but that a part of the ammonia in the wet soils must have changed to nitrates as a consequence of which the amount of nitrates in the wet samples must be higher than in the air-dry samples. This was found to be actually the case as the examination of Tables V and VI shows.

In connection with Table V these explanations should be made. Ordinarily about 1000 grams of soil were used for the estimation of the nitrates. This quantity was either increased or decreased depending on the amount of soil available for this es-

TABLE V.
NITRIC NITROGEN IN THE WET SOIL SAMPLES OF THE VARIOUS PLOTS.

Plot	Wet Soil used Grams	Of Extract Used		Nitric oxide (NO) Found			Nitric Nitrogen found [Calculated from NO]				Average
		c. c.	Corresponding oven-dried soil Grams	Volume c. c.	Temperature °C.	Barometric pressure in m.	Gram	Per cent of oven-dried Soil	Average	Per cent of total soil Nitrogen	
A	500	285	119.700	13.7	18	745	0.00770	0.00643	0.00627	1.61	1.57
B	700	285	119.700	13.1	20	743	0.00732	0.00613	0.00613	1.53	1.53
C	700	425	172.890	26.2	21	741	0.01446	0.00835	0.00835	2.24	2.23
D	900	390	157.404	28.2	22	739	0.01433	0.00829	0.00832	2.72	2.72
E	900	390	157.404	28.2	21	747	0.01568	0.00994	0.00994	2.63	2.68
F	900	533	219.303	34.0	22	743	0.01509	0.00958	0.00976	2.68	2.68
G	1200	525	220.264	32.7	17	743	0.01872	0.00853	0.00853	3.07	2.69
H	1100	800	338.440	46.4	22	743	0.01897	0.00865	0.00859	3.07	3.06
I	1100	725	310.826	36.0	21	743	0.01815	0.00824	0.00822	3.11	3.11
J	1000	725	310.826	36.0	22	747	0.02585	0.00764	0.00766	3.12	3.11
K	1100	650	277.257	40.2	21	746	0.01997	0.00643	0.00646	3.00	3.01
L	1100	725	305.442	42.3	22	745	0.02018	0.00649	0.00646	3.03	3.65
M	1000	625	260.906	36.5	21	739	0.02260	0.00815	0.00810	3.67	3.65
N	1000	675	298.282	38.8	21	738	0.02341	0.00767	0.00757	3.32	3.28
O	1000	650	268.710	34.0	21	739	0.02016	0.00773	0.00772	3.48	3.49
P	1000	650	268.710	34.0	21	738	0.02009	0.00770	0.00772	1.96	1.99
Q	1100	750	326.887	34.0	22	739	0.01258	0.00423	0.00430	2.03	2.73
R	1000	700	308.665	30.2	21	740	0.01573	0.00587	0.00595	2.69	2.70
S	1000	700	308.665	30.2	22	748	0.01623	0.00603	0.00586	2.72	2.60
T	1000	650	282.035	36.5	21	748	0.01928	0.00590	0.00586	2.68	2.60
U	1100	750	334.762	24.2	21	743	0.01721	0.00557	0.00549	2.56	2.98
V	1100	750	334.762	24.2	21	743	0.01671	0.00541	0.00711	2.99	2.98
W	1100	750	334.762	24.2	21	743	0.02009	0.00712	0.00711	1.59	1.60
X	1100	750	334.762	24.2	21	743	0.02603	0.00770	0.00398	1.61	1.60
Y	1100	750	334.762	24.2	21	743	0.01327	0.00396	0.00398	1.61	1.60
Z	1100	750	334.762	24.2	21	743	0.01340	0.00400	0.00398	1.61	1.60

TABLE VI.
NITRIC NITROGEN IN THE AIR-DRY SOIL SAMPLES OF THE VARIOUS PLOTS.

Plot	Air dry soil used Grams	Of Extract Used		Nitric oxide (NO) found			Nitric Nitrogen found [Calculated from NO]			Average
		c. c.	Correspond- ing oven- dried soil Grams	Volume c. c.	Tempera- ture °C.	Barometric pressure m. m.	Gram	Per cent of oven-dried soil	Average Nitrogen	
A	500	236	111.4	2.2	23	739	0.001189	0.00107	0.00107	0.27
B	.....	236	111.4	2.2	23	736	0.001189	0.00107	0.00107	0.27
C	900	450	213.2	0.8	23	740	0.000438	0.00021	0.00021	0.06
D	.....	450	213.2	0.8	23	740	0.000438	0.00021	0.00021	0.06
E	800	800	383.0	19.5	23	733	0.01052	0.00275	0.00275	1.02
F	1500	800	383.0	18.7	24	734	0.01008	0.00263	0.00263	0.98
G	1400	700	336.5	12.4	20	745	0.00695	0.00206	0.00206	0.84
H	.....	700	336.5	13.4	21	745	0.00745	0.00221	0.00221	0.84
I	1400	800	387.9	10.0	22	745	0.00551	0.00142	0.00142	0.66
J	.....	800	387.9	10.6	20	746	0.00595	0.00153	0.00153	0.71
K	1300	800	388.6	9.3	24	744	0.00507	0.00130	0.00130	0.59
L	1100	500	388.6	9.6	24	742	0.00526	0.00135	0.00135	0.61
M	.....	500	242.0	6.9	23	728	0.00369	0.00152	0.00152	0.66
N	1100	650	314.5	10.8	22	731	0.00582	0.00185	0.00185	0.84
O	.....	650	314.5	10.8	23	733	0.00582	0.00185	0.00185	0.84
P	1100	650	314.9	0.8	21	743	0.000438	0.00014	0.00014	0.06
Q	.....	650	314.9	0.8	22	745	0.000438	0.00014	0.00014	0.06
R	1400	880	424.6	0.7	21	741	0.000376	0.00009	0.00009	0.04
S	.....	880	424.6	0.8	22	740	0.000438	0.00010	0.00010	0.05
T	1500	900	435.9	0.8	23	745	0.000438	0.00010	0.00010	0.05
U	.....	900	435.9	0.8	23	745	0.000438	0.00010	0.00010	0.05
V	1500	900	437.4	1.3	22	740	0.000688	0.00016	0.00016	0.08
W	.....	900	437.4	1.3	21	739	0.000688	0.00016	0.00016	0.08
X	1400	800	385.8	0.4	22	732	0.000188	0.00005	0.00005	0.02
Y	.....	800	385.8	0.4	22	732	0.000188	0.00005	0.00005	0.02
Z	1400	850	409.7	2.8	24	733	0.001502	0.00037	0.00037	0.15
AA	.....	850	409.7	3.4	24	734	0.001815	0.00044	0.00044	0.18

*Not estimated.

†Determination lost.

timation. The accurately weighed soil was mixed with double the amount of water, including the moisture already in the soil, and during two days was regularly shaken each hour. The soil was then allowed to settle, the supernatant liquid filtered into a graduated cylinder and divided into two halves. The amount of oven-dried soil corresponding to the volume of the liquid used was then calculated. It is recorded in the fourth column. The nitric acid of the extract was decomposed with ferrous chloride, in the presence of hydrochloric acid, to nitric oxide the volume of which, on reduction to 0°C and 760 mm. bar. pressure, was calculated to nitrogen in grams which will be found in the eighth column. The other data need no explanation.

The determination of the nitrates in the air-dry soils is contained in Table VI.

An examination of the data in Table V and VI reveals the fact that the percentage of nitrates in the wet soils is considerably higher than in the air-dry ones. Recalling that the reverse was true as far as the proportion of ammonia in the wet and air-dry soils is concerned, it is but logical to conclude that the ammonia in the wet soils was transformed into nitrates. It should be borne in mind, however, that the soils under examination contain, in addition to ammonia and nitrates, also organic nitrogen, and it must be due to this factor that the increase of nitrates in the wet soils is larger than the decrease of ammonia in them. This has logically to be attributed to the fact that during the six or eight weeks which elapsed between the nitrate determinations in the air-dry soils on the one hand and in the wet soils on the other, not only the ammonia present as such in the wet soils, but also the ammonia which is constantly split off from the organic nitrogenous compounds, is gradually transformed into nitrates.

At any rate, the total percentage of ammonia and nitrates is small throughout all the plots, being a few thousandths of one per cent calculated to the oven-dried soil as a basis, or from about 0.4 to 1.4 per cent of the total soil nitrogen, recalling that the amount of ammoniacal and nitric nitrogen actually present in the soils is represented by the air-dry samples. This means that about 99 per cent of the total nitrogen is present in the soils in the shape of organic compounds. Their separation into amides, diamino and monamino acids was performed by the method used in Part I of this bulletin. The results are presented in Table VII.

As far as the data given in Table VII are concerned, it should be remembered that the phosphotungstic acid precipitate designated in the table as nitrogen of diamino acids, and the filtrate

TABLE VII.

AMOUNT OF NITROGEN IN THE VARIOUS COMPOUNDS.

Plot		Gram	Per cent of oven-dried soil	Per cent of total soil Nitrogen	Per cent of Nitrogen in solution
A	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.14778	0.3415	85.36	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00030	0.0007	0.17	0.20
	Nitrogen of amino acids (difference from 100)	0.04167	0.0963	24.07	28.20
		0.10581	0.2445	61.12	71.60
B	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.08050	0.2936	78.92	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00104	0.0038	1.02	1.29
	Nitrogen of diamino acids	0.02363	0.0862	23.17	29.35
	Nitrogen of monamino acids (difference from 100)	0.00778	0.0284	7.63	9.67
		0.04805	0.1752	47.11	59.69
C	Total nitrogen in solution (obtained by boiling with hydrochloric acid) ..	0.11472	0.3027	83.15	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00034	0.0009	0.24	0.30
	Nitrogen of amino acids (difference from 100)	0.03189	0.0841	23.12	27.80
		0.08249	0.2177	59.79	71.90
D	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.25696	0.2654	83.19	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00062	0.0006	0.20	0.24
	Nitrogen of amino acids (difference from 100)	0.07015	0.0724	22.71	27.30
		0.18619	0.1923	60.28	72.46
F	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.22715	0.2462	91.88	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00074	0.0008	0.30	0.33
	Nitrogen of amino acids (difference from 100)	0.06474	0.0702	26.19	28.50
		0.16167	0.1753	65.39	71.17
K	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.20817	0.2077	93.56	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00110	0.0011	0.49	0.53
	Nitrogen of amino acids (difference from 100)	0.05619	0.0561	25.26	26.99
		0.15088	0.1505	67.81	72.48

TABLE VII. (Continued.)

Plot		Gram	Per cent of oven-dried soil	Per cent of total soil Nitrogen	Per cent of Nitrogen in solution
L	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.21100	0.2111	91.39	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00150	0.0015	0.65	0.71
	Nitrogen of amino acids (difference from 100)	0.05904	0.0591	25.57	27.98
		0.15046	0.1505	65.17	71.31
O	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.18661	0.2006	93.29	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00072	0.0008	0.36	0.39
	Nitrogen of diamino acids	0.05936	0.0638	29.67	31.81
	Nitrogen of monamino acids (difference from 100)	0.03396	0.0365	16.98	18.20
		0.09257	0.0995	46.28	49.61
P	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.17033	0.1949	89.39	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00094	0.0011	0.49	0.55
	Nitrogen of amino acids (difference from 100)	0.05762	0.0659	30.24	33.83
		0.11177	0.1279	58.66	65.62
R	Total nitrogen in solution (obtained by boiling with hydrochloric acid)	0.17353	0.1877	86.51	100.00
	Ammoniacal nitrogen. Nitrogen of acid amides	0.00072	0.0008	0.36	0.41
	Nitrogen of diamino acids	0.04775	0.0514	23.71	27.40
	Nitrogen of monamino acids (difference from 100)	0.02780	0.0301	13.86	16.02
		0.09746	0.1054	48.59	56.16

from that precipitate designated as nitrogen of monamino acids, do not exclusively represent diamino and monamino acids. Likewise, what is recorded in the table as nitrogen of amino acids, which was obtained by subtracting the sum of ammoniacal and amido nitrogen from the total nitrogen in solution, does not represent amino acids only. In addition to diamino and monamino acids, the phosphotungstic acid precipitate and the filtrate from this precipitate may contain also nitrogenous compounds not belonging to the amino acid class. This has been demonstrated in Part I of this bulletin as well as in a previous² investigation.

The fact that the phosphotungstic acid precipitate and the filtrate thereof, in the case of the plots recorded in Table VII, actually contain diamino and monamino acids has been ascer-

²loc. cit.

tained by a number of tests of which those made with the soil extracts of the plots O and R may be given here. Thus, the phosphotungstates obtained from these two plots having been freed from phosphotungstic acid, yielded solutions which displayed the following reactions:

1. Phosphotungstic acid gave a heavy, white precipitate.
2. Phosphomolybdic acid gave a yellow precipitate.
3. Silvernitrate gave a grayish-white precipitate, soluble in excess of ammonia.
4. Mercuric chloride gave a grayish-white flocculent precipitate.
5. The aqueous solution was strongly alkaline.
6. Addition of neutralized formaldehyde to the alkaline solution brought about an acid reaction.

The filtrates from the phosphotungstates, obtained from the two plots under consideration, displayed optical activity. Thus, the observation of the aqueous solution obtained from plot O and freed from inorganic salts by crystallization, showed in the 2 dm. the rotation $\alpha = -0.27^\circ$. When acidulated with 5cc. of conc. hydrochloric acid the same solution rotated $\alpha = +0.15^\circ$.

In the case of plot R the corresponding aqueous solution obtained from about 150 grams of soil rotated in the 2 dm. tube as follows: $\alpha = -0.67^\circ$. On having been mixed with 10cc. of conc. hydrochloric acid the same solution showed the rotation $\alpha = +0.47^\circ$. The contents of the polariscope tubes of plots O and R having been freed from the bulk of hydrochloric acid by evaporation showed, upon addition to them of formaldehyde, increased acidity corresponding to several cc. of $\frac{1}{3}$ barium hydroxide, etc.

CONCLUSIONS.

1. The amount of ammoniacal nitrogen in all of the plots examined is insignificant, ranging from 0.000649 to 0.001508 per cent of the oven-dried soil, or from 0.203 to 0.653 per cent of the total soil nitrogen. Likewise, the proportion of nitric nitrogen is small, namely from 0.00005 to 0.00269 per cent of the oven-dried soil, or from 0.02 to 1.00 per cent calculated upon the total soil nitrogen. This leaves about 99 per cent of the total soil nitrogen in the form of organic compounds.

2. The proportion of amido nitrogen is quite considerable, ranging from 26.99 to 33.83 per cent calculated upon the nitrogen obtained in solution by boiling with hydrochloric acid.

3. Among the nitrogenous compounds, contained in the rest of the acid-soluble nitrogen, the monamino acids and diamino acids were found to be present in considerable quantities.

INFLUENCE OF VARIOUS FACTORS ON DECOMPOSITION OF SOIL ORGANIC MATTER

By S. L. JODIDI and A. A. WELLS.

One of the chief objects of humus investigations is to find out the chemical composition of soil humus, which will undoubtedly require a number of years of hard labor by competent researchers. Agriculture will in the meantime have to look for methods which in a general way indicate the behavior of soil humus as affected by physical, chemical or bacteriological factors. To such methods belong those showing the degree of chemical changes taking place in the soil organic matter under certain conditions. To be sure, such changes while chemical in nature, are not brought about by purely chemical means. They represent rather chemical-physiological phenomena in which the activities of certain micro-organisms are involved, the life functions of which, broadly speaking, are subject to similar physical and chemical laws as those of the higher plants. In both cases moisture, temperature, light, air and chemical factors play a very prominent part.

In order to get an idea as to the changes which may occur in the soil, we must first of all realize what elements are contained in soil humus. Since it represents the transition stage between the dead vegetable matter from which it is principally derived, and its final decomposition phase so to speak, i. e., the ash, we should logically expect to find in the soil organic matter the ten well-known elements, which are essential for plant life, though in different proportions. This being the case, it is at once evident that, theoretically, the changes taking place with any one of these elements may give us some idea as to what is going on with the whole of the soil humus. Further contemplation, however, will show us that there are only two elements whose oxidation can serve as a measure of the changes taking place in soil humus. The requirements which an element must answer to be suitable for the purpose indicated are these: It must occur in the humus in a considerable proportion and it must at the same time

be easily determinable in the least possible time. Neither the inorganic elements, potassium, calcium, magnesium and iron, nor the metalloids, sulphur and phosphorus, fully possess those qualities. The elements, hydrogen and oxygen, usually oxidized in the soil to water, are also to be eliminated from consideration for similar reasons. There remain, then, but two elements, namely, carbon and nitrogen, whose rate of oxidation can serve as a measure of the oxidation of humus.

Whereas the changes taking place with nitrogen undoubtedly throw considerable light upon the behavior of humus as a whole, it should be remembered that measuring the nitrogen requires too much time inasmuch as it involves several determinations, namely, of ammonia (liberated as such from humus) and of nitrites and nitrates, the oxidation products of the former. This renders the simultaneous examination of a number of plots not quite feasible. Carbon, on the other hand, oxidizes under the ordinary methods of soil cultivation to but one form, namely, carbon dioxide, which can easily and accurately be measured, even under field conditions. In addition the fact should also be borne in mind that carbon makes up a very considerable part of humus, namely more than fifty per cent of it. The above considerations point to carbon as the very element whose oxidation can best serve as a measure to determine the rate of oxidation of the humus.

Before presenting the data in question it may not be out of place, for reasons outlined below, to give here the analyses showing the total percentage of humus and of total and available phosphoric acid, as well as of carbon dioxide contained in the form of carbonates in each of the plots examined.

As already mentioned, decomposition of soil organic matter is no longer considered as a chemical phenomenon. Viewed in the light of modern researches, it is rightly looked upon as a biological process in which various species of micro-organisms are concerned. It is further well known that the activities of certain bacteria can materially be affected by the presence of acids, alkalies and salts. Thus, nitrification is aided by the presence of basic substances such as carbonate of lime, which are necessary for the neutralization of the nitric acid formed. Likewise, the presence of some inorganic salts, e. g., phosphates, in certain proportions will stimulate or retard the activities of certain micro-organisms. It is for these reasons that determinations of carbon dioxide of the carbonates present in the soils, as well as of total and available phosphoric acid, were made with a view of

TABLE I.

PLOT	Humus Per cent.	Total Phos- phoric acid per cent P_2O_5	More ac- tive forms of phos- phoric acid per cent P_2O_5	REMARKS
A	4.54		0.025	The total phosphoric acid as well as the more active forms of it were not determined in some of the plots because the soil samples in question were not large enough for making all of the analyses.
B	4.02		0.027	
C	4.62		0.032	
D	3.70		0.029	
E	3.67	0.110		
F	3.27	0.107	0.036	
G	3.04	0.100	0.028	
H	2.87	0.105		
I	2.73	0.099	0.009	
J	2.74	0.120		
K	2.46	0.126	0.010	
L	2.66	0.094	0.009	
M	2.65	0.106	0.011	
N	2.85			
O	2.27	0.079	0.008	
P	3.20	0.100	0.034	
Q	3.35			
R	2.70	0.111	0.032	
S	2.42	0.112	0.013	
T	2.99	0.115	0.027	
U	3.44			
V	3.27	0.109	0.026	

determining their influence upon the behavior of humus in the particular plots under examination.

While humus, as well as the total and more active forms of phosphoric acid in the soils, were determined according to the official methods (see Table I), the estimation of carbonates present in the soils was carried out, after the somewhat modified method of Mulder, Stolba and Kolbe.¹

THE METHODS AND APPARATUS EMPLOYED.

Some details of this method can best be seen from the accompanying prints. N in Figure 1 represents a boiling flask in which the soil under examination is to be decomposed with acid. The accurately weighed tubes, E and F, are filled with soda-lime for the absorption of carbon dioxide evolved from the acid-treated soil and contain in their upper shanks some calcium chloride to prevent loss of vapor. All the other tubes serve simply for their protection, namely, tube A contains calcium chloride in the lower part only; the tubes B and D are also filled with calcium chloride, while C contains pumice stone covered with water-free copper.

¹Annal. (Liebig), 119, 130; Zeitschr. f. analyt. Chem. 2, 49; 2, 341.

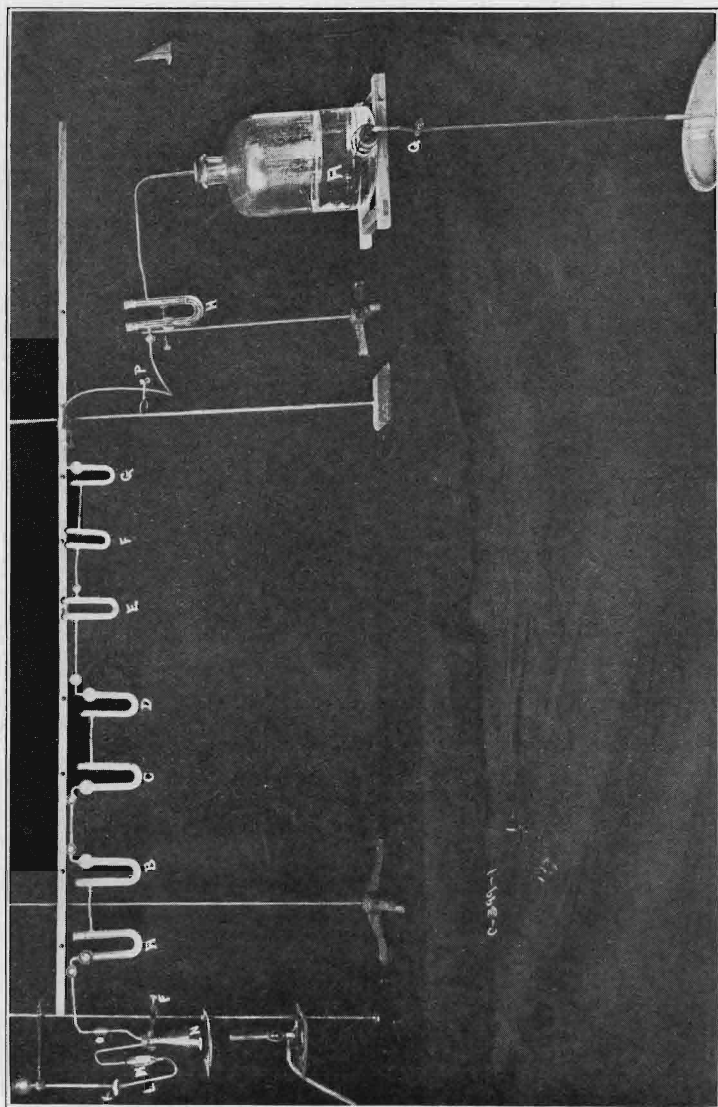


FIGURE 1.

sulphate. The four tubes named are designed to free the evolved carbon dioxide from vapor and hydrochloric acid, while the tube G, the left and right shanks of which are filled with calcium chloride and soda-lime, respectively, serves to protect tube F

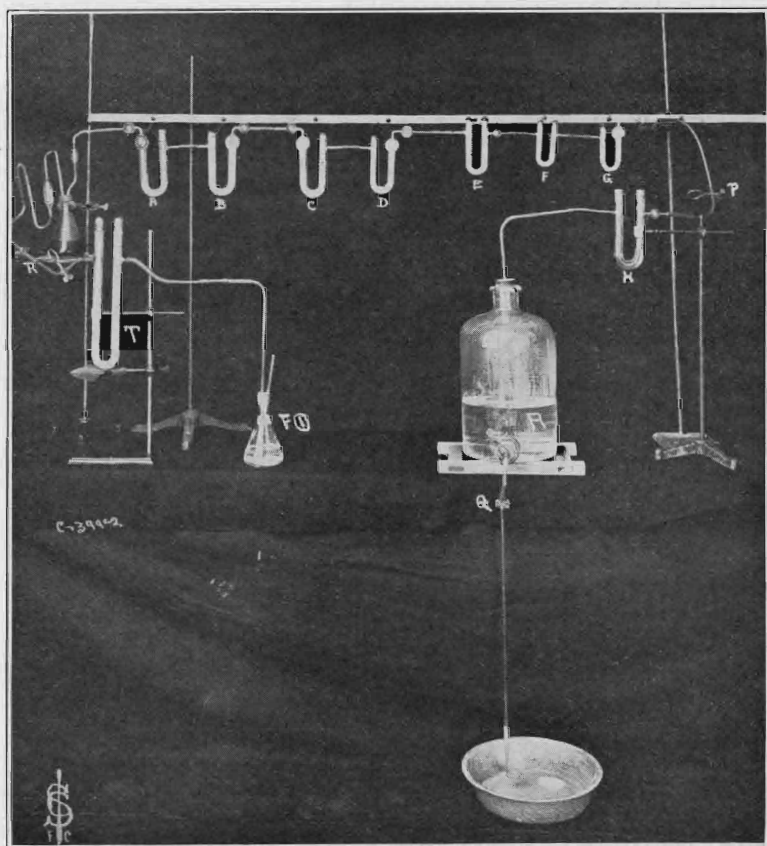


FIGURE 2.

from outside vapor. The decomposition of the weighed soil in question takes place in the flask N by means of hydrochloric acid or any other suitable acid, which is introduced into N through the funnel i by opening the pinch cock K. The carbon dioxide evolved passes through the system of tubes, being absorbed in E and F, and is regulated by the cock Q which allows the water to run from the aspirator R with the desired speed. The bubbles passing through the tube H, which contains some water in its lower part, enable one to observe the speed with which the carbon dioxide is evolved. As soon as the acid is no longer able to evolve carbon dioxide from the soil at room temperature, the funnel i is removed and the apparatus is connected with the tube T (see Fig. 2), which is filled with soda-lime and is connected

with the flask F containing potassium hydroxide. The flask N is now heated just long enough to bring its contents to the boiling point, while a continuous and uniform outflow of water from the aspirator R is maintained which causes all of the carbon dioxide contained in the system to be absorbed by the tubes E and F. Ordinarily the absorption of carbon dioxide is completed in about ten minutes. The increase in weight of these two tubes after the decomposition of the soil over that before the experiment expresses the exact amount of carbon dioxide present in the soil in the shape of carbonates.

It may be mentioned here that the determination of carbon dioxide in the carbonates was first tried with Geissler's apparatus. However, the results secured with that apparatus were so unsatisfactory that it was decided to make the carbon dioxide estimations with the apparatus just described. Again, the evolution of carbon dioxide from the carbonates was tried with dilute hydrochloric, nitric and phosphoric acid. While the data secured with hydrochloric acid were accurate, as were also those with phosphoric acid, the results obtained with nitric acid, because of the evolution of red fumes, were generally too high, for which reason only the estimations made with hydrochloric and phosphoric acid were included in the average. The figures obtained are recorded in Table II. A discussion of the results found will be given at the end of this bulletin.

TABLE II.

PLOT		Air-dry soil Grams	Corres- ponding oven-dry soil Grams	Acid Used	Carbon dioxide [CO ₂] found			
					Gram	Percent	Average	Total Average
A	4.0000	3.775	HCl	0.0025	0.066	0.060	0.124
		10.0000	9.437	HCl	0.0052	0.055		
		10.0000	9.437	HNO ₃	0.0221	0.234		
		10.0000	9.437	H ₃ PO ₄	0.0128	0.135		
		10.0000	9.437	H ₃ PO ₄	0.0125	0.132		
B	10.0000	9.489	HCl	0.0064	0.067	0.052	0.120
		10.0000	9.489	HCl	0.0050	0.053		
		10.0000	9.489	HCl	0.0033	0.035		
		10.0000	9.489	HNO ₃	0.0308	0.325		
C	10.0000	9.476	HCl	0.0059	0.062	0.069	0.069
		10.0000	9.476	HCl	0.0064	0.068		
		10.0000	9.476	HCl	0.0074	0.078		
D	10.0000	9.524	HCl	0.0037	0.039	0.036	0.036
		10.0000	9.524	HCl	0.0031	0.033		
E	10.0000	9.548	HCl	0.0053	0.055	0.049	0.049
		10.0000	9.548	HCl	0.0040	0.042		
		10.0000	9.548	H ₃ PO ₄	0.0046	0.048		

TABLE II. (Continued.)

PLOT	Air-dry soil Grams	Corres- ponding oven-dry soil Grams	Acid Used	Carbon dioxide [CO ₂] found			
				Gram	Percent	Average	Total Average
F	10.0000	9.576	HCl	0.0016	0.017	0.033	0.030
	10.0000	9.576	HCl	0.0038	0.040		
	10.0000	9.576	HCl	0.0041	0.043		
	10.0000	9.576	H ₃ PO ₄	0.0021	0.022		
G	10.0000	9.613	HCl	0.0042	0.044	0.035	0.035
	10.0000	9.613	HCl	0.0029	0.030		
	10.0000	9.613	HCl	0.0031	0.032		
	10.0000	9.613	H ₃ PO ₄	0.0034	0.035		
H	10.0000	9.688	HCl	0.0050	0.052	0.041	0.046
	10.0000	9.688	HCl	0.0029	0.030		
	10.0000	9.688	H ₃ PO ₄	0.0053	0.055		
I	10.0000	9.697	HCl	0.0054	0.056	0.048	0.048
	10.0000	9.697	HCl	0.0040	0.041		
J	10.0000	9.698	HCl	0.0030	0.031	0.031	0.031
	10.0000	9.698	HCl	0.0031	0.032		
K	10.0000	9.714	HCl	0.0036	0.037	0.036	0.036
	10.0000	9.714	HCl	0.0024	0.025		
	10.0000	9.714	HCl	0.0045	0.046		
L	10.0000	9.682	HCl	0.0030	0.031	0.034	0.034
	10.0000	9.682	HCl	0.0036	0.037		
M	10.0000	9.676	HCl	0.0025	0.026	0.027	0.031
	10.0000	9.676	HCl	0.0027	0.028		
	10.0000	9.676	H ₃ PO ₄	0.0037	0.038		
N	10.0000	9.666	HCl	0.0036	0.037	0.031	0.031
	10.0000	9.666	HCl	0.0024	0.025		
O	10.0000	9.689	HCl	0.0035	0.036	0.040	0.040
	10.0000	9.689	HCl	0.0043	0.044		
P	10.0000	9.649	HCl	0.0025	0.026	0.024	0.024
	10.0000	9.649	HCl	0.0021	0.022		
Q	10.0000	9.680	HCl	0.0016	0.017	0.029	0.029
	10.0000	9.680	HCl	0.0028	0.029		
	10.0000	9.680	HCl	0.0039	0.040		
R	10.0000	9.687	HCl	0.0029	0.030	0.034	0.034
	10.0000	9.687	HCl	0.0037	0.038		
S	10.0000	9.719	HCl	0.0022	0.023	0.024	0.030
	10.0000	9.719	HCl	0.0024	0.025		
	10.0000	9.719	H ₃ PO ₄	0.0042	0.043		
T	10.0000	9.647	HCl	0.0018	0.019	0.017	0.017
	10.0000	9.647	HCl	0.0014	0.015		
U	10.0000	9.663	HCl	0.0010	0.010	0.025	0.025
	10.0000	9.663	HCl	0.0021	0.022		
V	10.0000	9.663	HCl	0.0043	0.044	0.032	0.032
	10.0000	9.640	HCl	0.0027	0.028		
	10.0000	9.640	HCl	0.0034	0.035		

The idea of ascertaining the influence of physical factors, like moisture, temperature, air, light, as well as of certain chemical substances upon the decomposition of the organic matter in the

soil is not new. Kostytscheff,² Schloesing,³ Wollny,⁴ Deherain,⁵ Soyka,⁶ Warington,⁷ and Boussingault⁸ experimented along those lines. While some of them tried to find out the rate of oxidation of the organic matter by determining the amount of carbon dioxide evolved under the influence of certain factors, the others did it by estimating the proportions of ammonia, nitrites and nitrates produced. The observations of the investigators named have this in common: they represent chiefly laboratory experiments in which small amounts of soil mixed with other materials were put into tubes, cylinders or other vessels and the rate of decomposition stated. Other experimenters, too, worked along similar lines though some field observations were also made.

Results secured on a small scale in the laboratory may not necessarily hold good for field conditions. It was, therefore, deemed advisable to carry out similar experiments directly in the field and all the more so since we had at our command a number of plots under a variety of conditions. The fact that not less than twenty-two plots were to be under observation rendered determinations of ammonia, nitrites and nitrates practically infeasible, and it was decided to measure the rate of oxidations taking place in the soil by the amount of carbon dioxide evolved. It is evident that the greater the decomposition of the organic matter in the soil, the richer in carbon dioxide will be the soil atmosphere and vice versa.

THE FIELD APPARATUS.

The arrangements for the daily observations, the results of which are presented in the following pages, were made as follows: In the first place each of the twenty-two plots under experiment was provided with an iron tube twelve inches long and with an inner diameter of $\frac{5}{8}$ of an inch. At one end the tube was drawn out to a point. The periphery of the lower two inches of the tube was provided with twelve small holes of one-eighth of an inch diameter. Into the upper part of the tube was put a rubber stopper, a one-eighth inch glass tube, thirteen inches long, passing through stopper and all made air tight. This tube stood out above the iron tube some three inches and reached with its lower end the periphery holes of the iron tube. In order to prevent completely the outside air from coming into the tube, the space below the rubber stopper between the glass and iron tube was in part filled out with paraffin which together with the rubber stopper held both tubes always in the same position.

²Ann. Science agron. fr. et etrang. 1887, II. Fasc. 2, p. 165.

³Comptes rendus., 77, 1873, p. 203; *ibid.*, 77, 1873, p. 353.

⁴Journ. f. Landw. 1886, p. 232. Journ. f. Landw. 1886, p. 243.

⁵Am. agron., 13, No. 6, 1887, p. 241.

⁶Zeitschr. Biol., 14, 1878.

⁷Landw. Versuchsst., 24, 161 (1879).

⁸Comptes rendus, 86, 22.

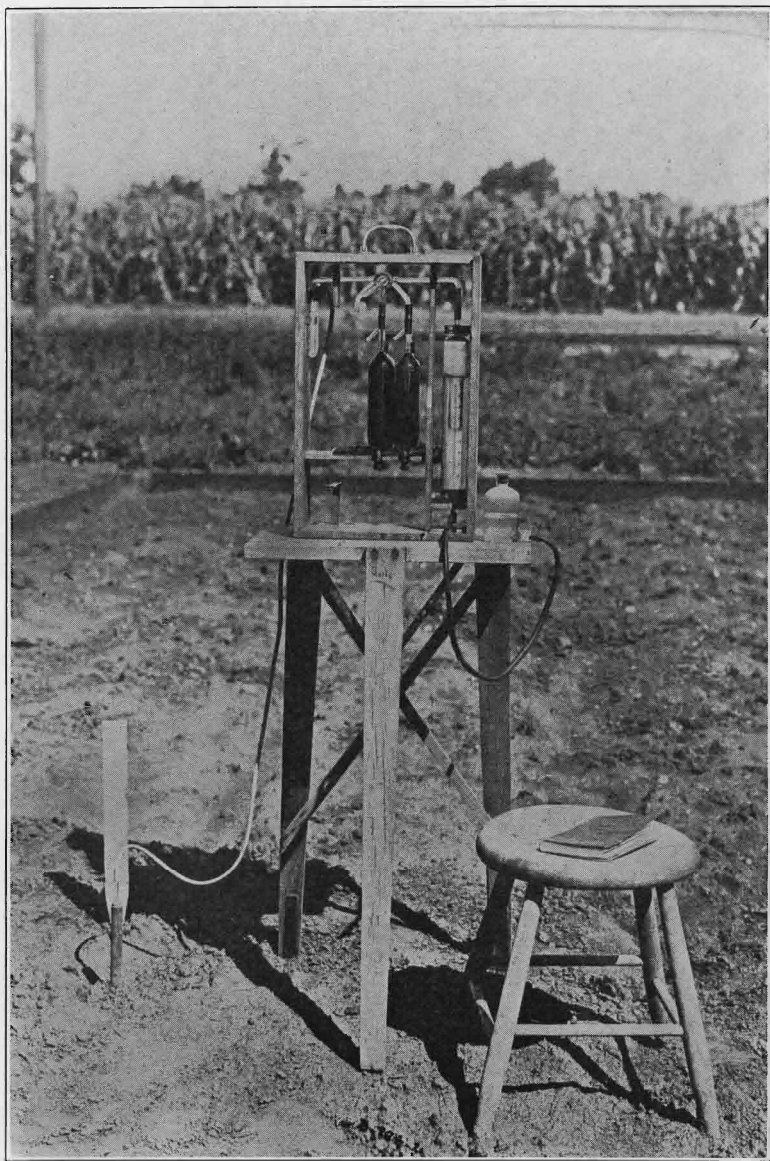


FIGURE 3.

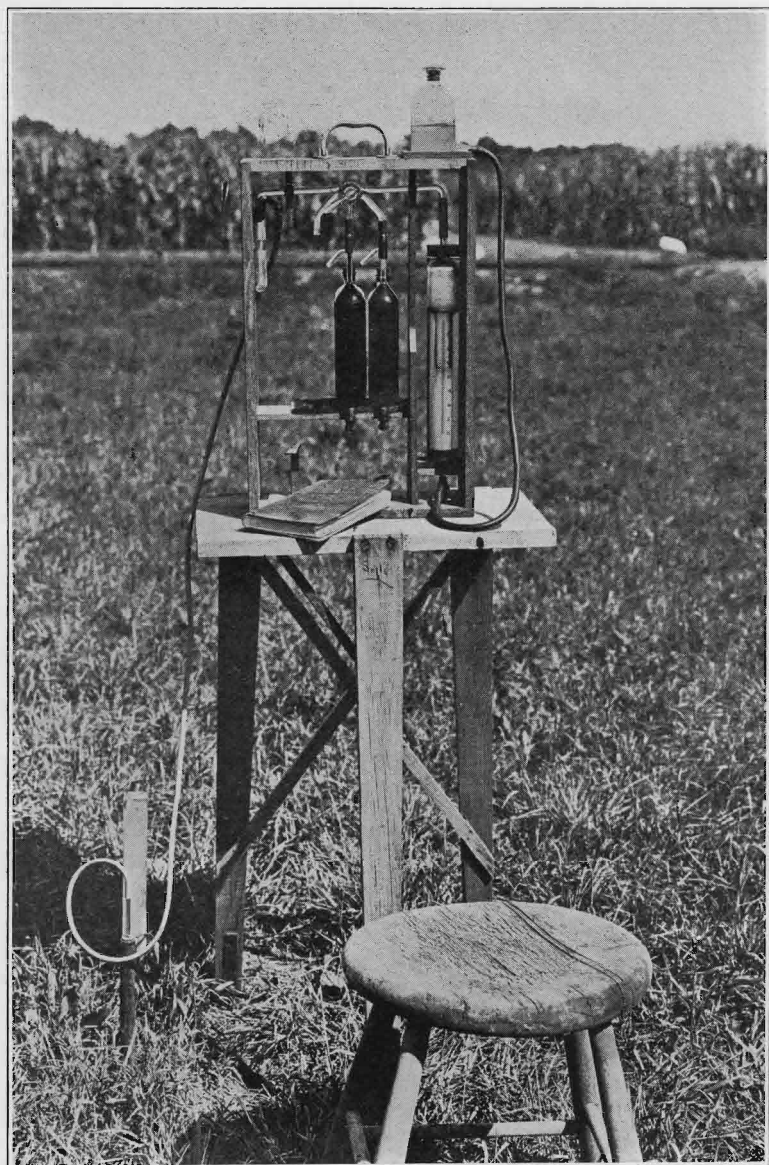


FIGURE 4.

For drawing a portion of the soil atmosphere into the tube just described, its pointed end was forced into the soil of each plot to a depth of seven inches, the upper end of the glass tube being connected by means of rubber tubing, with the Orsat apparatus. The whole arrangement can be seen from the photographs (see Figures 3 and 4) and needs no further description. By means of the pressure bottle the soil atmosphere is drawn into the Orsat apparatus, the first 100cc. being discarded in order to force the air out of the apparatus, and the next 100cc being used for analysis. By alternately raising and lowering the pressure bottle the soil atmosphere is a number of times brought into contact with the right bulb of the apparatus containing a solution of potassium hydroxide which absorbs the carbon dioxide of the atmosphere. The decrease in volume of the soil atmosphere analyzed expresses the proportion of carbon dioxide in it. Likewise the estimation of oxygen is made by bringing the atmosphere, freed from carbon dioxide, into contact with the left bulb containing an alkaline solution of pyragallol which absorbs the oxygen. Since the burette of the apparatus has a capacity of 100cc. and is graduated into cubic centimeters with divisions allowing to record one-tenth of one cc., it is evident that the readings express directly the percentage of carbon dioxide or oxygen in the soil atmosphere.

In addition to carbon dioxide and oxygen determinations which were made once a day, the temperature of the air as well as of the soil in the various plots to a depth of six inches was regularly observed. The temperature of the soil was recorded only once a day at the time the carbon dioxide and oxygen estimations were run, while the temperature of the air was recorded three times every day, namely, at 8 a. m., 1 p. m. and 5 p. m.

In connection with the analytical data secured we must not omit to mention here that each one of the figures given in the tables for April, May, June, July and August represents the average of the observations for a whole month, with the essential restriction, however, that, as a rule, observations were not made on rainy days or on such days which immediately followed a heavy rain, because of the muddy condition of the plots which rendered observations very inconvenient. Pressing work in the laboratory, too, sometimes prevented the field observations in question. It is for these reasons that conclusions from the results presented in the following tables will have to be made cautiously.

THE INFLUENCE OF MOISTURE AND TEMPERATURE.

In reviewing the data before us we can clearly see the influence of moisture and temperature upon the decomposition of soil organic matter. Thus, in June, both the soil temperature

APRIL.

PLOT	Temperature of air °C	Temperature of soil °C	Precipitation in inches	Per cent of CO ₂	Percent of O	Remarks
A	21.1	11.9	2.25	0.500	21.10	Maximum and minimum air temperature was 18.7° and 4.2°C respectively.
B	19.1	13.1	2.25	0.260	21.20	
C	19.1	13.5	2.25	0.220	21.10	
D	19.1	13.3	2.25	0.125	20.85	
E	19.1	13.3	2.25	0.125	21.05	
F	19.1	13.2	2.25	0.125	20.97	
G	19.1	13.2	2.25	0.100	20.87	
H	19.1	14.0	2.25	0.125	20.95	
I	19.1	15.2	2.25	0.150	21.03	
J	19.1	14.3	2.25	0.225	21.20	
K	19.1	15.0	2.25	0.233	21.13	
L	19.1	14.5	2.25	0.225	21.00	
M	19.1	15.1	2.25	0.175	20.85	
N	19.1	16.4	2.25	0.167	21.00	
O	19.1	16.0	2.25	0.133	21.20	
P	19.1	15.5	2.25	0.167	21.17	
Q	21.1	16.1	2.25	0.100	21.00	
R	21.6	14.1	2.25	0.300	20.50	
S	21.6	11.6	2.25	0.200	20.50	
T	21.6	11.2	2.25	0.150	20.60	
U	21.6	12.0	2.25	0.250	20.70	
V	21.6	11.6	2.25	0.150	20.50	
Average	19.85	13.82	2.25	0.191	20.93	

MAY

PLOT	Temperature of air °C	Temperature of soil °C	Precipitation in inches	Per cent of CO ₂	Percent of O	Remarks
A	Maximum and minimum air temperature was 20.3° and 5.8°C respectively.
B	18.80	14.64	1.55	0.14	20.27	
C	18.80	14.84	1.55	0.30	20.50	
D	18.80	14.54	1.55	0.16	20.46	
E	18.54	14.50	1.55	0.19	20.55	
F	18.54	14.51	1.55	0.21	20.49	
G	18.54	14.70	1.55	0.16	20.60	
H	18.54	14.86	1.55	0.15	20.54	
I	18.54	15.45	1.55	0.19	20.60	
J	18.54	15.68	1.55	0.14	20.52	
K	18.54	16.20	1.55	0.25	20.58	
L	18.54	17.05	1.55	0.25	20.75	
M	18.54	17.29	1.55	0.19	20.55	
N	18.54	17.20	1.55	0.21	20.58	
O	17.80	17.94	1.55	0.16	20.63	
P	17.80	17.90	1.55	0.17	20.64	
Q .....	.....	.....	.....	.....	.....
R	17.80	17.89	1.55	0.16	20.69	
S	17.80	17.70	1.55	0.13	20.70	
T	17.80	17.99	1.55	0.19	20.77	
U	17.80	18.01	1.55	0.17	20.81	
V	17.80	17.93	1.55	0.13	20.70	
Average	18.32	16.34	1.55	0.182	20.60	

147
JUNE.

PLOT	Temperature of Air °C	Temperature of soil °C	Precipitation in inches	Per cent of CO ₂	Percent of O	Remarks
A	31.8	22.50	2.36	0.10	19.90	Maximum and minimum air temperature was 27.7° and 12.5°C respectively.
B	28.1	22.20	2.36	0.04	19.93	
C	28.1	22.50	2.36	0.82	19.36	
D	28.1	22.60	2.36	0.20	20.38	
E	25.6	21.80	2.36	0.14	20.49	
F	25.7	21.00	2.36	0.11	20.53	
G	25.7	20.97	2.36	0.12	20.63	
H	25.7	20.88	2.36	0.44	20.26	
I	25.7	21.44	2.36	0.18	20.56	
J	25.7	21.86	2.36	0.20	20.61	
K	25.7	21.68	2.36	0.40	20.35	
L	27.4	23.38	2.36	0.40	20.53	
M	27.4	23.62	2.36	0.32	20.52	
N	27.4	24.05	2.36	0.46	20.34	
O	27.4	24.50	2.36	0.27	20.38	
P	27.4	23.75	2.36	0.18	20.54	
Q	27.4	24.42	2.36	0.71	20.15	
R	27.4	24.81	2.36	0.22	20.54	
S	27.4	24.67	2.36	0.32	20.60	
T	27.4	24.07	2.36	0.26	20.64	
U	27.4	24.03	2.36	0.29	20.49	
V	27.4	24.22	2.36	0.40	20.49	
Average	27.15	22.95	2.36	0.299	20.37	

JULY.

A	27.08	21.92	1.42	0.12	20.30	Maximum and minimum air temperature was 31.2° and 14.9°C respectively.
B	27.08	24.35	1.42	0.12	20.36	
C	27.08	24.52	1.42	0.17	20.00	
D	27.08	24.75	1.42	0.40	19.90	
E	26.40	24.70	1.42	0.20	20.25	
F	26.40	24.48	1.42	0.28	20.30	
G	26.40	24.40	1.42	0.38	20.33	
H	26.40	24.34	1.42	0.18	20.57	
I	26.40	24.38	1.42	0.26	20.53	
J	26.40	24.64	1.42	0.20	20.42	
K	26.40	24.86	1.42	0.22	20.42	
L	27.00	25.32	1.42	0.28	20.46	
M	27.00	25.94	1.42	0.20	20.47	
N	27.00	26.32	1.42	0.24	20.75	
O	27.00	28.16	1.42	0.24	20.43	
P	27.00	27.86	1.42	0.22	20.47	
Q	27.00	25.26	1.42	0.36	20.53	
R	27.00	28.72	1.42	0.20	20.30	
S	27.00	28.50	1.42	0.40	20.33	
T	27.00	27.74	1.42	0.38	20.53	
U	27.00	27.90	1.42	0.20	20.60	
V	27.00	27.72	1.42	0.38	20.40	
Average	26.82	25.77	1.42	0.256	20.39	

AUGUST.

PLOT	Temperature of air °C	Temperature of soil °C	Precipitation in inches	Per cent of CO ₂	Percent of O	Remarks
A	26.4	22.04	3.02	0.17	20.03	Maximum and minimum air temperature was 29.5° and 15.5°C respectively.
B	26.4	23.84	3.02	0.34	20.18	
C	26.4	23.85	3.02	0.68	19.93	
D	26.4	23.82	3.02	0.39	20.10	
E	26.4	23.84	3.02	0.40	20.21	
F	26.4	23.84	3.02	0.27	20.23	
G	26.4	23.91	3.02	0.34	20.29	
H	26.4	23.68	3.02	0.37	20.23	
I	26.4	24.03	3.02	0.17	20.40	
J	26.4	24.02	3.02	0.31	20.29	
K	26.4	24.17	3.02	0.27	20.33	
L	26.4	24.99	3.02	0.29	20.23	
M	26.4	26.10	3.02	0.42	20.40	
N	26.4	26.32	3.02	0.41	20.43	
O	26.4	25.24	3.02	0.27	20.27	
P	26.4	25.37	3.02	0.24	20.44	
Q	26.5	23.83	3.02	0.36	20.43	
R	26.8	26.45	3.02	0.38	20.34	
S	26.2	25.92	3.02	0.30	20.31	
T	26.2	25.59	3.02	0.42	20.42	
U	26.2	25.42	3.02	0.35	20.51	
V	26.2	24.38	3.02	0.42	20.50	
Average	26.39	24.57	3.02	0.344	20.30	

(22.95°) and the amount of precipitation (2.36 inches) were higher than in April (13.82° and 2.25 inches), or in May (16.34° and 1.55 inches). This caused the organic matter to decompose more rapidly as a consequence of which the soil atmosphere was richer in carbon dioxide during June (0.299%) as compared with April (0.191%) and May (0.182%). Again, August with the largest quantity of precipitation (3.02 inches) and with a temperature but 1.2° lower than in July, the hottest month of the season, shows a soil atmosphere richest in carbon dioxide (0.344%).

The influence of temperature alone can be seen by a comparison of April and June with practically the same amount of rainfall (2.25 and 2.36 inches respectively) but with different temperature (13.82° and 22.95° respectively). In conformity with the higher temperature the soil atmosphere was richer in carbon dioxide during June (0.299%) than during April (0.191%). We arrive at the same conclusion by comparing May and July with about the same amount of rainfall (1.55 and 1.42 inches respectively) but with different soil temperatures

TOTAL AVERAGES FOR SEASON.

(April, May, June, July, August, 1910.)

PLOT	Temperature of Air °C	Temperature of soil °C	Precipitation in inches	Per cent of CO ₂	Percent of O
A	26.59	19.59	10.60	0.220	20.33
B	23.90	19.63	10.60	0.180	20.38
C	23.90	19.84	10.60	0.440	20.18
D	23.90	19.80	10.60	0.255	20.34
E	23.21	19.63	10.60	0.211	20.51
F	23.23	19.41	10.60	0.199	20.50
G	23.23	19.44	10.60	0.220	20.54
H	23.23	19.55	10.60	0.253	20.51
I	23.23	20.10	10.60	0.190	20.52
J	23.23	20.10	10.60	0.215	20.62
K	23.23	20.38	10.60	0.275	20.56
L	23.69	21.05	10.60	0.189	20.59
M	23.69	21.61	10.60	0.261	20.56
N	23.69	21.46	10.60	0.297	20.62
O	23.54	22.37	10.60	0.215	20.58
P	23.54	22.08	10.60	0.195	20.65
Q	25.50	22.40	10.60	0.382	20.53
R	24.12	22.39	10.60	0.252	20.47
S	24.00	21.68	10.60	0.270	20.49
T	24.00	21.32	10.60	0.280	20.59
U	24.00	21.47	10.60	0.252	20.62
V	24.00	21.17	10.60	0.296	20.52
Average	23.85	20.75	10.60	0.252	20.51

(16.34° and 25.77° respectively). As a consequence of the higher temperature in July, the soil atmosphere was richer in carbon dioxide (0.256%) than in May (0.182%).

The influence of precipitation alone follows from the tables for July and August with very little difference in soil temperature (25.77° and 24.57° respectively), but with considerable difference in rainfall (1.42 and 3.02 inches respectively). The smaller rainfall in July shows a smaller percentage of carbon dioxide (0.256%) in the soil atmosphere than in August (0.344%). This conclusion is still further substantiated by the individual tables for August 13th, 16th, 17th, 18th, 19th and 20th, with but inconsiderable differences in soil temperature (23.62°, 25.05°, 23.75°, 22.12°, 22.52° and 24.27° respectively). With 0.29 per cent of carbon dioxide in the soil atmosphere on August 13th, it rose to 0.99 per cent of carbon dioxide because of a heavy rainfall of one inch on August 15th. The influence of the heavy rainfall was felt for several days, though owing to inconsiderable or lack of rainfall in the following days the proportion of car-

August 13				August 16		
PLOT	Temperature of soil	Precipitation in inches	Per cent of CO ₂	Temperature of soil	Precipitation in inches	Per cent of CO ₂
A	*	0.13	*	23.0	0.0	0.1
B	*	0.13	*	24.0	0.0	1.7
C	*	0.13	*	23.8	0.0	0.3
D	*	0.13	*	23.5	0.0	1.5
E	24.2	0.13	0.3	23.9	0.0	0.7
F	24.0	0.13	0.2	23.7	0.0	1.0
G	23.7	0.13	0.2	24.0	0.0	1.2
H	23.6	0.13	0.6	23.4	0.0	1.2
I	23.8	0.13	0.1	24.4	0.0	0.6
J	23.5	0.13	0.2	24.1	0.0	0.9
K	23.6	0.13	0.2	23.5	0.0	1.3
L	24.1	0.13	0.4	25.0	0.0	1.1
M	24.6	0.13	0.4	27.0	0.0	1.4
N	24.5	0.13	0.4	27.1	0.0	1.0
O	22.9	0.13	0.2	25.8	0.0	0.9
P	23.0	0.13	0.3	27.0	0.0	0.8
Q	22.0	0.13	0.2	25.0	0.0	0.8
R	24.2	0.13	0.4	26.6	0.0	1.1
S	23.7	0.13	0.4	27.2	0.0	1.0
T	23.2	0.13	0.4	26.5	0.0	1.1
U	24.0	0.13	0.2	27.1	0.0	1.2
V	22.6	0.13	0.2	25.5	0.0	0.9
Average	23.62	0.13	0.29	25.05	0.0	0.99
*Observations prevented by rain.						

August 17				August 18		
A	23.1	0.3	0.3	21.5	0.0	0.6
B	24.0	0.3	0.6	22.0	0.0	0.5
C	24.0	0.3	0.3	21.6	0.0	0.2
D	23.9	0.3	1.2	21.8	0.0	1.1
E	24.1	0.3	0.4	21.5	0.0	0.2
F	23.4	0.3	0.5	21.2	0.0	0.5
G		0.3	0.5	21.2	0.0	0.6
H	Further observations prevented by rain.			21.2	0.0	0.9
I				21.5	0.0	0.2
J				21.5	0.0	0.4
K				21.5	0.0	0.3
L				22.5	0.0	0.6
M				22.8	0.0	0.6
N				23.0	0.0	0.4
O				22.5	0.0	0.3
P				22.5	0.0	0.5
Q				21.5	0.0	0.8
R				22.5	0.0	0.8
S				23.8	0.0	0.5
T				23.5	0.0	0.6
U				23.2	0.0	0.2
V				22.4	0.0	0.5
Average	23.75	0.3	0.54	22.12	0.0	0.51

August 19				August 20		
PLOT	Temperature of soil	Precipitation in inches	Per cent of CO ₂	Temperature of soil	Precipitation in inches	Per cent of CO ₂
A	21.0	0.0	0.4	22.0	0.0	0.2
B	21.8	0.0	0.2	23.4	0.0	0.1
C	21.8	0.0	0.1	24.0	0.0	0.1
D	21.6	0.0	0.6	23.5	0.0	0.7
E	21.6	0.0	0.1	24.0	0.0	0.1
F	21.5	0.0	0.4	24.0	0.0	0.5
G	21.4	0.0	0.3	23.7	0.0	0.4
H	21.5	0.0	0.4	23.0	0.0	0.8
I	21.8	0.0	0.2	24.0	0.0	0.1
J	21.9	0.0	0.3	23.0	0.0	0.3
K	21.8	0.0	0.3	24.2	0.0	0.2
L	23.1	0.0	0.5	24.2	0.0	0.4
M	24.1	0.0	0.6	24.3	0.0	0.5
N	24.1	0.0	0.3	25.1	0.0	0.7
O	23.3	0.0	0.3	23.1	0.0	0.2
P	23.6	0.0	0.5	25.1	0.0	0.2
Q	22.1	0.0	0.7	24.2	0.0	0.7
R		0.0		24.7	0.0	0.2
S	24.8	0.0	0.3	27.7	0.0	0.2
T	23.3	0.0	0.5	25.8	0.0	0.6
U	24.4	0.0	0.3	26.4	0.0	0.2
V	22.5	0.0	0.3	24.5	0.0	0.3
Average	22.52	0.0	0.36	24.27	0.0	0.35

bon dioxide gradually fell from 0.99 per cent (August 16th) to 0.54% (August 17th), 0.51% (August 18th), 0.36% (August 19th) and 0.35% (August 20th).

No observations were made during August 14 and 15. Precipitation of August 14 and 15 was equal to 0.12 and 1.00 inch respectively.

It is interesting to note that the average percentage of oxygen in the soil atmosphere for all the plots and for the whole season was 20.51%. Adding to this 0.252—the average percentage of carbon dioxide for the season—we get about 20.8%, which is approximately the percentage of oxygen in the air. This is easily explained by a consideration of the fact that in the oxidation process of humus carbon to carbon dioxide, one volume of oxygen is used for the production of one volume of carbon dioxide as expressed in the following equation: $C + O_2 = CO_2$. Hence, all other things being equal, the soil atmosphere differs from the air in that it is poorer in oxygen and correspondingly richer in carbon dioxide. In other words, the total percentage of carbon dioxide and oxygen in the soil atmosphere is about the same as in the air.

IMPORTANCE OF INCREASED CARBON DIOXIDE IN SOIL.

A higher percentage of carbon dioxide in the soil atmosphere, pointing to a more rapid decomposition of soil humus, is agriculturally an important indication, inasmuch as carbon dioxide represents plant food. True, the air contains enough carbon dioxide to feed all plants. The fact, however, should not be forgotten that the increase in mass of any plant is, everything being equal, proportional to the period of its growth. Since, however, the space of time for the growth of most of the cultivated plants is limited, the importance of an abundance of carbon dioxide in the soil atmosphere is quite evident. While the proportion of carbon dioxide throughout all the plots examined was small, owing to inconsiderable rainfall in the summer of 1910, we find, however, that the average proportion for the whole season and all the plots was 0.252 per cent of carbon dioxide, which is more than six times the percentage of carbon dioxide present in the air. Besides, a higher proportion of carbon dioxide in the soil atmosphere is an indication that not merely carbon, but that other elements contained in the humus, are also being decomposed which means a new supply of ammonia, nitrates, phosphoric acid, etc.

A further examination of the data in hand shows that the production of carbon dioxide, through decomposition of humus, is on the whole fairly uniform in all the plots, being for the whole season lowest in plot B (0.180% CO_2) and highest in plot C (0.440% CO_2). It is of interest to note that the least decomposition took place in plot B, which was treated annually with peat, showing the inert character of the latter. The rather uniform and in but small degree varying decomposition of soil humus has as a consequence the constant production of plant food throughout the growing season. This is a great advantage as compared with commercial fertilizers, such as nitrate of soda, which being at once soluble and available are not infrequently leached out of the soil in considerable quantities, while the plants find ample time to take up the food resulting from the gradual decay of humus materials.

In addition to the influence of moisture and temperature upon the decomposition of soil organic matter it was intended to find out the behavior of the organic matter as affected by tillage of the soil. For lack of time, however, this question could not be investigated as thoroughly as it undoubtedly deserves. A few observations only, given in Table III, will be given any space here. Thus, the percentage of carbon dioxide in the soil atmosphere of the plots B, C, D, E and F, was on May 20th, 23d and 24th quite small, ranging (with the exception of but one case) from 0.05 to 0.1 per cent. The cultivation of the plots on

TABLE III.

Plot	May 20 CO ₂ percent	May 23 CO ₂ percent	May 24 CO ₂ percent	May 26 CO ₂ percent	May 27 CO ₂ percent	Remarks
B	0.1	0.05	0.05	0.4	0.3	The plots were cultivated on May 23 and harrowed on May 25.
C	0.1	0.1	0.1	0.9	0.7	
D	0.1	0.1	0.1	0.2	0.4	
E	0.2	0.1	0.1		0.3	
F	0.1	0.1	0.1		0.2	

May 23d and their harrowing on May 25th were followed by an increase of carbon dioxide in the soil atmosphere, being on May 26th 0.4, 0.9 and 0.2 per cent in the case of plots B, C, D, and on May 27th 0.3, 0.7, 0.4, 0.3 and 0.2 per cent in the case of the above named plots. The more rapid decay of humus as affected by cultivation and harrowing is easy to understand when we consider that tillage operations render possible the free access to the soil of air, and hence of oxygen, which oxidizes the organic matter.

INFLUENCE OF CHEMICAL FACTORS ON DECOMPOSITION OF HUMUS.

Turning to the influence of chemical factors upon decomposition of soil humus and comparing the results secured for total and available phosphoric acid (Table I) as well as for carbon dioxide of carbonates (Table II) present in the soils on the one hand, and for carbon dioxide found in the soil atmosphere on the other, we fail to find a very definite relation between the figures in question. It would seem that while it is easy to show the influence of certain chemicals upon the decay of soil organic matter in the laboratory, it is not so simple a matter to demonstrate it under field conditions. In the case of the plots examined it may be due in part to the fact that all the plots contain fairly uniform and sufficient amounts of the chemicals under consideration. Another, perhaps better, explanation which suggests itself, is that the influence of the chemicals being not as significant as that of physical factors, like temperature and moisture, may perhaps in some measure be masked by the latter.

A few figures, however, seem to indicate that there is a certain relation between the percentage of humus in the plots and the proportion of carbon dioxide in the corresponding soil atmospheres. Thus, plot C, with the highest percentage of humus, (4.62%), shows a soil atmosphere richest in carbon dioxide (0.440%). Likewise, the plots Q and V, with considerable humus, percentage (3.35%, 3.27% respectively) show a high proportion of carbon dioxide in their atmospheres (0.382%, 0.296%

respectively). Plot B, though with a high humus content, (4.02%) shows a soil atmosphere poorest in carbon dioxide (0.180%) which is perhaps due to the inert character of the peat which that plot annually received. That the mentioned relation is not evident in other plots may be due to other chemical factors which for lack of time have not been touched upon in this paper and which may play a certain part in the decay of soil organic matter. It is hoped that a thorough inquiry into this important question, as well as into others indicated above, will be taken up as soon as possible.

CONCLUSIONS.

1. Increase of moisture and temperature (as well as tillage operations) was followed by a more rapid decomposition of the organic matter in all of the plots herein investigated.

2. While owing to a variety of conditions obtaining in the plots there is a difference in the rapidity with which the organic matter in them decomposes, it is especially marked in the case of plot B, which though with a high humus content shows the lowest percentage of carbon dioxide in the soil atmosphere. It seems fairly reasonable to ascribe it in part to the inert nature of the peat with which it was annually treated.