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THE CONTROL OF THE HUMUS SUPPLY OF CERTAIN
IMPORTANT MISSOURI SOILS.

Presented as a thesis for the degree of
MASTER OF SCIENCE. (in Agriculture)

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A C K N O W L E D G M E N T S.

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Chap. I. HISTORY OF OUR KNOWLEDGE OF HUMUS.

Agriculture is one of the oldest occupations of man and yet agricultural science is very little understood as compared with the other sciences. Fertility of the soil, which is the basis upon which all agriculture depends, has not been understood any better than any other branch of the subject. The organic principles in the soil are perhaps less understood than any other group of substances, although it has been recognized from the earliest times that organic matter had a very beneficial effect on the productive power of a soil.

Although several of the classical authors wrote on the subject of agriculture and the use of manures quite early, their writings were philosophical rather than scientific, and very little progress was made until the beginning of the nineteenth century. The manures used in the early times were the dung of birds and domestic animals. Mineral substances such as ashes, etc., were also used with beneficial effects.

At the time of the commonwealth in England crops were grown year after year until the land failed to yield sufficient to cover the cost of labor. During this period poorly cared for farmyard manure was used to a limited extent but no system of crop rotation was followed.

De Saussure was the most important writer on agriculture at the beginning of the nineteenth century. He believed that lime and potash found in the ashes of plants were produced by the action of nitrogen during combustion. This theory became interwoven with the doctrine of organic mould. Hence, some of the greatest agricultural writers of that time looked upon organic matter as the only source of food for plants. They held that the mineral constituents found in the ashes of plants were formed by dung. (A nitrogenous substance)

J. C. Schubert was the first to find that humus could not supply all that a crop required. He found that an application of gypsum along with dung increased the yield of clover. He assumed that the increase was due to a stimulating property of the gypsum or that it acted as a decomposer of the humus rendering it more available.

Later De Saussure discovered the all-important fact that plants obtain their carbon from the atmosphere and that the mineral constituents of the soil played a very important part in the nutrition of plants generally.

In 1840 Liebig published his "Organic Chemistry in its application to Agriculture and Physiology". The chief point in this work is to show that the humus of the soil was powerless to build up completely the various tissues of the plant. Liebig's arguments^{against} the theory of organic mould

(1)
are summarized by Davy and Shier as follows:

1st. The humic acid of chemists does not occur in appreciable quantities in fertile soils; it is found in the course of the chemical processes had recourse to, to procure it. If the humates existed in the soil and constituted the food of plants, they would communicate a brown tint, and be readily detected in the water of springs, brooks and rivers, but they are not so; neither do they occur in seawater, hence it must be from carbonic acid that the immense crops of algae which grow on the bottom and shores of the sea derive their carbon. 2nd, The humates are so little soluble, that it can be shewn, that all the rain that falls during the growth of common crops is incapable, even if it were all to be saturated with humates, and to pass through the plants, of affording a tithe of the carbon they require. 3rd, There was no original humus, and hence it is not absolutely essential. 4th, Many plants have but a point of attachment in the soil, and live almost entirely by absorption from the air. 5th, Neither in cultivated land that is regularly manured, nor in forest or meadow lands that are not, does the humus decrease; in the latter cases, indeed, it increases.

(1) Agricultural Chemistry, page 201.

It is evident from this that Liebig's views were nearly as radical in the extreme of mineral plant food as the earlier investigations were in favor of the organic plant food, but his conclusions approached more nearly the true state of affairs and formed a valuable basis for later investigations. It was a revolutionary movement on the accepted ideas of scientific agriculture. It has especially a most stimulating effect on investigations in agricultural chemistry, and to him we owe in a great degree, the summarizing of previous disconnected work and the mapping out of valuable lines for future investigations.

About this time Sir John B. Lawes began his investigations at Rothamstead. The experiments here were very extensive and laboratory investigations were supplemented by field experiments. The problem of the assimilation of atmospheric nitrogen, and other important studies were taken up and carried out very systematically to a fair state of completion.

Among the more prominent recent investigators on humus in soils may be mentioned Berthélot, André, Dehérain, Pagnoul, Dumont, Snyder, Wheeler, Hilgard and Ladd. The French investigators have devoted a greater part of their time to the study of plant physiology in its relation to humus substances, while the American investigators have studied

the effect of continuous cropping, the effect of various mineral and organic fertilizers, and crop rotation upon the humus content of the soil in its composition. Hilgard has taken up the relation of the humus content and composition of arid and semi-arid soils to that of the soils of the humid region, and Wheeler has made a study on the effect of liming upon the decomposition of humus.

Chapter II. A STUDY OF THE PRESENT STATE OF OUR KNOWLEDGE OF HUMUS.

Before taking up the study of the effect of various methods of cropping and the effect of organic manures on the humus content of soils the present status of our knowledge of humus will be briefly outlined. Considerable work has been done on the various phases of the subject both in America and Europe. The principle phases of the work which we shall consider in this chapter are what humus is, its origin and various processes concerned in its formation, its chemical composition and physical properties with the factors effecting these, the bacteriological factors concerned in its formation and destruction rendering the plant food elements available, and the formation of humates and their relation to soil fertility.

Humus is a very difficult substance to define, because of its variability and complexity. As the term is generally used it applies to the substance which is formed in soils intermediate between the beginning of decomposition and total oxidation. According to Wiley (1) humus is the active principle of vegetable mould and is the term used to designate in general the products of decomposition of vegetable matter as they are found in soils. It is a

(1) Principles and Practice of Agricultural Analysis. Vol. I, page 60.

spongy gelatinous substance, brown to black in color, depending upon the stages of decomposition. In normal soils we find every stage in the decomposition of organic matter, from the substances which are just beginning to decompose to those which are totally decomposed.

The organic substances which furnish this material may be the roots and stems of plants, excreta of animals, or any other organic compound. In nature it has been formed by the decay of leaves and dead plants which fall to the earth each year. Hence, regions which naturally support an abundance of vegetation will in most cases be regions in which the humus content of the soil will be high. In the case of swamp lands a heavy growth of vegetation develops each year and falls to the ground, being incorporated with the soil, the rate of decay and oxidation being lessened by the lack of aeration in the wet soil. In some cases the organic content becomes so high that peat or even coal is formed after many years. Many of the swamp lands in the Central States have such a high humus content that they are unproductive. Where the organic content is not too high these lands may be reclaimed by draining, but in other cases the organic matter has not reached a sufficiently advanced stage of decomposition and it has to be subjected to weathering for some time.

The formation of humus goes on best at a moderate temperature with a fair degree of moisture and adequate aeration,

and when humus is formed under swamp conditions the constant presence of water prevents sufficient aeration; consequently swamp lands usually require the access of oxygen before they become productive.

In temperate climates in the first stages of decay all the available oxygen immediately combines with those portions of the substance which decompose most readily. The more tender portions of vegetable matter are converted in a carbonic acid and water, while a residuum of humus remains. But when once formed this humus has considerable power to resist further oxidation. Humus does, however, slowly oxidize in the soil when there is free access of air and generally speaking it oxidizes more or less rapidly, depending upon its age. The more tender the portion of the plant the sooner it is oxidized. It is true only in the main that the decomposing action proceeds more and more slowly in proportion as the humus becomes older.

The amount of humus formed from any given amount of vegetable matter may vary widely, depending on a number of conditions. In case of our soils in this locality, and more especially so in the arid regions, and in the southern states, the temperature and moisture content of the soil are the principle factors governing the amount of humus from any given amount of vegetable matter. In the southern states where the soils are coarse in texture and

where warm weather and moist conditions prevail the whole year the humus is depleted very rapidly. In the arid regions the soils are usually loose and dry. This allows the humus to burn out rapidly and the organic matter almost totally oxidized. According to Hilgard (1)"if we assume that in the humification of plant debris (estimating their average nitrogen content at one percent) no nitrogen is lost it would seem that in the humid region one part of normal soil humus might be formed from five to six parts of (dry) plant debris; while in the extreme regime of the arid regions from eighteen to twenty parts of the same would be required. But as most probably, some nitrogen is also lost in the process of humification, a considerably larger portion of original substance may be actually required".

The texture of a soil modifies quite materially the rapidity of decay of organic matter and the formation of humus. This is true indirectly only, as the texture of a soil to a certain extent determines its aeration, temperature, and water holding capacity. A fine textured clay soil will not allow of as rapid depletion of the humus as a coarser textured soil like the loams and sandy loams. In these latter soils humification proceeds much more rapidly, which in a large measure accounts for the value of sandy soils for truck gardening purposes. They respond in a comparatively short time to the application of

(1) Soils, page 128. E. W. Hilgard.

any form of organic manure, such as stable manure and green manure.

Very coarse grained soils can often be made productive in this way.

In the case of heavy clay soils it is often a serious problem to obtain sufficient aeration for the process of nitrification, which is to furnish nitrogen to the growing crop.

In chemical composition humus is a very complex substance. It is composed principally of carbon, hydrogen, oxygen, and nitrogen, with very small amounts of mineral substances which unite with the humic acids to form humates. Its complexity, non crystalline ~~na~~ nature and insolubility seem to have rendered it an uninviting subject for research. Detmer gives the following formula $C_{60} H_{54} O_8$ and Thenard $C_{24} H_{10} O_6$.

There are four distinct organic acids recognized in humus, e.g., humic, ulmic, crenic, and apocrenic. Each of these is formed in a certain stage in the decomposition of organic matter. These have the power of uniting with the bases in the soil forming humates, etc. These are quite insoluble and for this reason the formation of humates is often of great value in preventing the loss of the more soluble bases by leaching.

According to Storer (1) "It is in brown humus, which is an early product of vegetable decomposition, that ulmic acid and ulmin are formed; while the black humus into

(1) Agriculture. Vol. I, p. 461. F. H. Storer.

which brown humus is converted by decay, contains humic acid and humin.

Crenic and apocrenic acids are the products of further oxidation of humus. Salts of crenic acid are formed especially in moist soils, where the circumstances favor reduction, and those of apocrenic acid in loose dry earth where oxidation is not only possible, but easy".

Hilgard (1) says in describing the progressive changes which take place in humification "The natural neutral humin and ulmin, as found e. g., in the lower portions of peat beds are in the course of time converted into ulmic and humic acid, capable of combining with bases; by still further oxidation they form apocrenic and crenic acids readily soluble in water, and in part forming soluble salts with lime, magnesia, and other bases. These acids act strongly on the more readily decomposable silicates of the soil, and in the course of time they dissolve out, and aid in the removal by leaching, of most of the plant food ingredients as well as the ferric hydrate of the soil".

Although the exact composition of these organic acids has never been worked out, there has been a number of formulas submitted as to their probable composition, and the one below given by Stockbridge (2) gives some idea as to their constituents:

(1) Soils. page 126. E. W. Hilgard.

(2) Rocks and Soils, page 134. H. E. Stockbridge.

ULMIN and ULMIC ACID.

Carbon	67.1%	Corresponding to
Hydrogen	4.3%	$C_{40} H_{28} O_{12} + H_2O$
Oxygen	8.7%	

HUMIN and HUMIC ACID.

Carbon	64.4%	Corresponding to
Hydrogen	4.3%	$C_{21} H_{24} O_{12} + 3 H_2O$
Oxygen	31.3%	

CRENIC ACID.

Carbon	44.0%	
Hydrogen	5.5%	Corresponding to
Nitrogen	3.9%	$C_{12} H_{12} O_8 ?$
Oxygen	46.6%	

APOCRENIC ACID.

Carbon	34.4%	
Hydrogen	3.5%	Corresponding to
Nitrogen	3.0%	$C_{24} H_{24} O_{12} ?$
Oxygen	39.1%	

He also says that besides these humus compounds there are others still less known and the action of which is not yet understood; among them xylic acid $C_{24}H_{30}O_{17}$, glucinic acid $C_{12}H_{22}O_{12}$, besides a brown humus containing

carbon 65.8% and hydrogen 6.25%, and a black humus yielding carbon 71.5% and hydrogen 5.8%. It is therefore quite evident that any definite knowledge of the exact composition of humus is lacking.

There has been considerable controversy as to whether any of the humus compounds as humates could be utilized directly by plants as plant food. Some very striking results have been published that seem to indicate that certain plants do take nourishment in this form. But the weight of authority at present is that for agricultural plants, at least, neither humus nor any of its components have any practical significance as direct food for plants. Humus is, however, of great indirect value to soil fertility. It improves the tilth, permeability, and absorptive power of soils. In the process of decomposition it gives off carbon dioxide which aids in rendering the more insoluble forms of plant food available. The humic acid being able to unite with the more soluble bases forming insoluble humates, prevents the loss of these elements which would otherwise be effected by leaching. These are later set free for the use of the plant by the decomposition of humus.

In the humid region we usually find the larger part of the humus in the top foot, although in some of the ~~rich~~ rich black prairie lands we find very little difference in the humus content to a depth of three feet, or even deeper.

But below this we very seldom find a very high percent of humus, except in muck or peaty soils. The soils of the arid region are notably low in humus but the line between the soil and subsoil in these regions is very indefinite and humus is found at greater depths than in the humid regions.

Hilgard (1) gives the subjoined table which shows the humus and nitrogen in humus from the surface foot to a depth of twelve feet in a soil taken from a bench of the "Russian River", California, which is sub-irrigated and liable to more or less rainfall during the summer. "It will be seen that not only does the humus percentage decrease quite regularly down to seven feet, at which point there was evidently a strong root development, causing a notable increase in the humus content; from which again there is a regular decrease town to the twelfth foot. It will be noted that the nitrogen percent in the humus, while not decreasing with the same regularity as the humus content itself, yet exhibits a general recession from 5.30 to 1.15 in the ninth foot to which depth direct oxidation doubtless never penetrates."

(1) Soils, page 138. E. W. Hilgard.

Humus and nitrogen content of Russian River soil.

Depth in feet	Percent humus in soil	Percent nitrogen in humus	Percent humus - nitrogen in soil
1	1.21	5.30	.064
2	1.16	4.32	.054
3	1.14	3.87	.044
4	1.17	3.76	.044
5	.74	2.16	.016
6	.60	2.66	.016
7	.47	2.54	.012
8	.78	1.54	.012
9	.54	2.24	.012
10	.52	1.15	.006
11	.53	1.51	.008
12	.44	1.81	.008

Where oxidation of the organic matter proceeds more rapidly as is the case in the arid regions the composition of the humus is modified considerably. The humus content of the arid soils is much lower than humid soils, but Hilgard (1) found that the nitrogen content of this humus was higher than the nitrogen content of the humus of the soils of the humid regions. The results of examination of humus in twenty-four carefully selected samples of soil

(1) California Exp. Sta. Rep. 1892-4, and Agr. Sci. 8(1894) No. 4, pages 165-171.

from arid and semiarid regions, and eight from humid regions confirm this view. The average results are as follows:

	Number of samples	Humus in soil Percent	Nitrogen in soil Percent	Nitrogen in humus Percent
Arid soils	18	0.75	0.101	15.87
Semiarid soils	8	.99	0.102	10.03
Humid soils	8	3.04	0.132	5.24

From these figures it is evident that on the average the humus of arid soils contains three times as much nitrogen as that of the humid soils. In some cases it was observed that the difference went as high as six to one, the percent of nitrogen exceeding that of the albuminoid group.

These figures indicate that in the arid region the humus percentage, which under humid conditions would justly be considered inadequate for the production of normal crops, may nevertheless suffice even for the most exacting crops.

The probable explanation for this is that the conditions in the arid regions are much more favorable for the rapid oxidation of the organic matter of the soil. This causes the humus content to decline with practically the same amount of nitrogen it would have had, had it not oxidized so rapidly, making the percent of ~~humus~~ nitrogen in humus higher while the total amount of humus nitrogen in

the soil may be less. The fact that plants can do with a smaller percentage of humus is due to the fact that the rapid decay of the organic matter makes the percentage of available nitrogen higher.

Humus varies greatly in its composition, depending upon its source, method of formation, and age. Snyder (1) has made the following divisions of humus on the basis of nitrogen.

"I. The non-nitrogenous group as sugar humus.

II. The nitrogenous group, divided into three or four sub-groups, as (1) humus containing one to two percent of nitrogen, as sawdust humus; (2) humus containing two to four percent of nitrogen, as oat straw humus; (3) humus containing four to eight percent of nitrogen as cow manure and clover humus;; and (4) humus containing over eight or nine percent of nitrogen, as meat scrap humus."

This classification is like the greater part of humus studies, purely arbitrary and serves a very general purpose only. Such a classification might indicate from what source humus was derived, but on the other hand many substances might produce the same amount of nitrogen in the humus. This is a very interesting problem, however, and many interesting things could be worked out in studying the relation of humus composition to its origin in connection with various green manures and other organic manures in common use.

(1)

Jour. Am. Chem. Soc., Vol. XIX. No. 9, page 740, and
Chemistry of Soils and Fertilizers, page 93, Harry Snyder.

Snyder (1) produced humus from a variety of materials such as cow manure, green clover, meat scraps, wheat flour, sawdust, oat straw, and sugar. About 200 grams of each substance were mixed with 3000 grams of soil and allowed to undergo humus formation out of doors for one year. The humus materials were extracted by potassium hydroxide solution after washing with a dilute hydrochloric acid solution and water, and the black and brown precipitates dried and prepared for analysis. "The precipitated humus materials contained from five to twelve percent of ash, and had the following ultimate composition, on an ash free basis:"

Humus Produced by

	Cow manure Per ct	Green clover Per ct	Meat scraps Per ct	Wheat flour P ct	Oat Straw Per ct	Sawdust Per ct	Sugar Per ct
Carbon	41.95	54.22	48.77	51.02	54.30	49.28	57.84
Hydrogen	6.26	3.40	4.30	3.82	2.48	3.33	3.04
Nitrogen	6.16	8.24	10.96	5.02	2.50	0.32	0.08
Oxygen	45.65	34.14	35.97	40.14	40.72	47.07	39.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	Highest percent	Lowest percent	Difference percent
Carbon	57.84 sugar	41.95 cow manure	15.89
Hydrogen	6.26 cow manure	2.48 oat straw	3.78
Nitrogen	10.96 meat scraps	0.08 sugar	10.88
Oxygen	47.07 sawdust	34.14 green clover	12.93

(1) Jour. Am. Chem. Soc., Vol XIX, No. 9. page 738-9.

These figures indicate great differences in composition, depending upon the source of the humus. No two materials have any general similarity in composition. The humus derived from sugar is an example of a non-nitrogenous source of humus, the small amount of humus shown in the table probably having been derived from the nitrogen in the soil. The humus formed from meat scraps represents the opposite extreme of nitrogen content. Green clover also shows a high percentage. The humus from these substances must be exceedingly complex in character because each is made up of both nitrogenous and non-nitrogenous bodies, and each of these classes of compounds are capable of being split up into still other compounds, each one having a different action in humification processes.

The amount, and composition of humus in soils varies quite appreciably with the composition of the soil. Certain compounds favor the rapid decomposition of humus and when these are present in the soil naturally, or have been added in the form of commercial fertilizers the humus content is consequently modified. One of the most notable substances of which this is true is lime. Thus it is evident that when lime is used in considerable quantities for the acidity of soils or for other purposes, some form of organic manure should be added to prevent the exhaustion of the humus supply.

In order to determine the effect of air-slaked lime and certain other substances, Wheeler, Sargent, and Hartwell (1) carried out the following experiment:

Galvanized pots 26 inches deep and 18 inches in diameter, having an opening into a drain tile to insure drainage, at the bottom, were set into the ground to within two inches of the top of the cans, and 154 pounds of subsoil and 100 pounds of soil placed in each pot. "The pots were filled in the spring of 1893. In 1893 - 94 each manure plot received 7.36 grams of potassium chloride and 22.07 grams of bone black. In the succeeding years these amounts were increased to 10 and 25 grams respectively. When ever nitrogen was applied it was at the rate of 2.65 grams per pot. Lime, unless other wise 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 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 case of the pots which had been manured alike, approximately like amounts of soil were taken from each and the samples for analyses were then taken from the mixture of these lots".

The extraction of the humus for the determination of the humus was effected by treatment with a dilute ammonia solution after washing with a dilute hydrochloric acid solution. The nitrogen in humus was determined by extraction with a two and a half percent solution of potassium hydroxide. Aliquot portions were taken after neutralization with sulphuric acid were evaporated to dryness in a Kjeldahl flask and nitrogen determined by the Kjeldahl method. The following are the analytical results calculated to percentages of soil dried at 100 C.

Nos. of plots	Manures applied	Humus-nitrogen in dry soil	Humus in dry soil	Nitrogen in dry humus
		Percent	Percent	Percent
21	Unmanured	0.130	3.86	3.37
16, 18, 25	Ammonium sulphate	.128	3.93	3.26
15, 22	Ammonium sulphate, air-slaked lime (1 ton per acre)	.133	3.77	3.53
17, 19, 26	Ammonium sulphate, air-slaked lime (4 tons per acre)	.126	3.63	3.47
1, 8	Ammonium sulphate, calcium sulphate, at a rate equivalent in CaO to 4 tons per acre of air-slaked lime	.139	3.65	3.81
20, 27	Without nitrogen and lime	.129	3.75	3.44
23, 24	Air-slaked lime	.139	3.51	3.68
6, 13	Sodium nitrate	.143	3.93	3.64
7, 14	Sodium nitrate and air-slaked lime	.133	3.42	3.89

In the case where phosphorus and potassium were added each year (20 and 27) it will be seen that the humus and humus nitrogen were slightly lower than that of the unmanured plot, while the percentage of nitrogen in the dry humus showed but slight variation.

By comparing the pot receiving air-slaked lime in addition to phosphorus and potassium with the one having only these two elements added, we find an increase in humus nitrogen in the soil, as also there is an increase of nitrogen in the dry humus by 0.24 percent but a decrease of 0.24 percent in humus content.

The pots receiving nitrogen as sodium nitrate showed a higher humus nitrogen content and also a higher humus content, but a lower nitrogen percentage in the dry humus.

Where lime was applied at the rate of 1 ton per acre with ammonium sulphate, the humus nitrogen was slightly greater, the humus less and the percentage of nitrogen in the humus greater. Where lime was applied at the rate of 4 tons per acre, no decided variations in the amount of humus nitrogen resulted, though the percentage of humus was found to be .30 percent less than where no lime was applied, and the percentage of nitrogen in the humus was increased by liming.

Where gypsum was applied at a rate sufficient to furnish an amount of calcium oxide equivalent to four tons of air-slaked lime per acre, the humus nitrogen was 0.011 percent higher than where neither lime nor gypsum was applied, the humus was 0.28 percent lower and the nitrogen in humus 0.55 percent higher.

These figures show that where air-slaked lime or gypsum were used the result was a decrease in the total amount of humus, as compared to the unmanured plot, yet the percentage of nitrogen in humus is increased. This indicates that decomposition has gone on much more rapidly when lime was applied and naturally this caused a lower humus content and what humus did remain had nearly as much total nitrogen in it as it would have had, had it not been so rapidly decomposed.

Where lime was not applied, but the nitrogen was supplied in the form of ammonium sulphate, which in the acid soil proved poisonous to plants, the percentage of nitrogen in the humus was even less than in the unmanured plot, and on the other hand when sodium nitrate furnished the nitrogen to the plots without lime the percentage of nitrogen in the humus was greater than in the unmanured plot.

It will be seen from the foregoing results where sodium nitrate was added it ranked first in the humus nitrogen in the dry soil, and first in the humus in the dry soil, and fourth in the percentage of nitrogen in the dry humus, and while the plot in which ammonium sulphate was used ranked equally with it in humus content but it was the lowest one of all in the nitrogen in dry humus, and lower than the average in the amount of humus nitrogen in the dry soil.

That the fixation of plant food by Zeolitic silicates is also shared by humus has been demonstrated quite conclusively.

The organic acids unite with the bases in the soil which are in the form of a more or less soluble salts and form insoluble humates, etc. These are retained until the humus is broken down, when they are released in a more soluble form which can be used by plants.

Dumont (1) found that in humus soils containing variable amounts of lime that the absorption of phosphates was greater than in ordinary soils, and that the removal of humus by incineration greatly reduced the absorptive capacity.

As yet the most satisfactory method for the determination of the bases in combination is to extract the soil with caustic alkali solution (about four percent), after washing with a dilute hydrochloric acid solution. The humus is soluble in the alkali, and after washing with the acid solution the solution of humus in the alkali should contain only humus compounds, and any mineral elements found in this solution should be regarded as in the form of humates, et. The following analysis (2) by Snyder was made of the ammonia solution after neutralizing the liquid.

(1) Exp. Sta Record Vol XLII, page 28.

(2) Jour. Am. Chem. Soc., Vol XLX. No. 9.

Ash of Humus from Minnesota Prairie Soils.

Insoluble matter (in HCl)	61.97%
Potash (K_2O)	7.50%
Soda (Na_2O)	8.13%
Lime (CaO)	0.09%
Magnesia (MgO)	0.36%
Peroxid of iron (Fe_2O_3)	3.12%
Alumina (Al_2O_3)	3.48%
Phosphoric acid (P_2O_5)	12.37%
Sulphuric acid (SO_3)	.98%
Carbonic Acid (CO_2)	1.64%

The most striking figures in this analysis are the large amounts of the soluble alkali, sodium and potassium, and the large proportions of phosphorus.

In his investigations with the soils of North Dakota Ladd (1) gives the analysis of twenty-four samples of soil from various parts of the State showing the humus and mineral in humates which is summarized as follows:

	Total		Nitrogen		Phos. acid		Calcium oxid		Potash	
	Humates Per ct	Humus	Total P. ct	In H. P. ct	Total P. ct	In H. P. ct	Total P. ct	In H. P. ct	Total P. ct	In H. P. ct
Min.	3.84	1.56	.180	.041	trace	trace	trace	000	.18	.075
Max.	15.26	7.90	.456	.362	.40	.199	2.70	1.03	.73	.233
Avg.	9.15	4.77	.292	.163	.269	.138	.944	.436	.409	.153

(1) Bul. 35, North Dakota Agrl. Exp. Sta.

This table shows that there is a marked variation. It will be seen that an increase in the mineral humates is always associated with an increase in humus, indicating that when we have a high humus content the power of the soil to fix soluble bases is increased.

According to Hilgard (1) the amount of phosphoric acid associated with the humus varies from one-tenth to five-tenths of the total amount in the soil, indicating in many cases the amount of this element available to plants in actual practice.

In the foregoing pages the decomposition of organic matter in the soil has been considered from a chemical standpoint only, but none the less, ^{important} are the bacteriological factors associated with decay and in fact the greater part of the chemical processes in the decomposition are directly dependent upon the action of bacteria.

In general, organic material contain two classes of compounds: (1) the nitrogenous or albuminoid compounds; and (2) the non-nitrogenous compounds - the carbohydrates and hydrocarbons. The nitrogenous or albuminoid substances contain the nitrogen formerly taken from the soil as nitrate by some plant, but which is in such a highly organized form that it is unavailable to plants until converted into ammonia or nitrate again by certain bacteria. The nitrogenous materials serve as food for certain other forms of bacteria.

(1) Exp. Sta. Record Vol V, 833.

The process of the reduction of the highly organized nitrogenous substances is described by Woods (1) as follows:

"The highly organized nitrogenous materials, in soil containing a good supply of phosphates, potash, carbonate of lime, air, moisture and the right kinds of bacteria are first modified or digested into soluble peptones by a class of bacteria which secrete a peptonizing ferment. *BACILLUS TUMESCENS* ZOPF, *B. ELLENBACHIENSIS* carson, *B MYCOIDES*. Flügge, et., are good examples of this class. These peptonized products (peptones and albumoses) are then converted into ammonia through the action of these same species and other ammonifying bacteria. The ammonia may then be converted into nitrate by another class of bacteria, principally *NITROSOMONAS ENSOPAL*, widely distributed in Europe, and by species of *Nitrococcus*, said to be peculiar to the soils of American and Australia. (2) The nitrate is then oxidized to nitrate by still another kind of bacterium, *Nitrobacter*".

(1) Year Book, U. S. D. A., 1906, page 126.

(2) The Soil, A. D. Hall. page 72.

If however, we have poorly aerated soils deficient in the mineral plant foods we have another form of decomposition which is commonly termed putrefaction. Acids accumulate and the flora is changed to bacteria and fungi that can grow in the presence of acids. The more active peptonizing or ammonifying bacteria are suppressed by conditions unfavorable to their development. In the humus soils of some of the Central States these conditions exist. Huston (1) has found that by affording aeration by the addition of straw and the addition of potash and phosphoric acid the unproductive black ~~mat~~ lands in northern Indiana could be temporarily made productive and that by providing adequate drainage they could be made permanently productive.

It is also necessary in some cases to add the peptonizing, ammonifying and nitrifying bacteria.

In contrast with the nitrification we have the process of denitrification. This consists in the deoxidation of the nitrates in the soil, i. e., the reduction of the nitrates to nitrites and ammonia. According to Voorhees and Lipman (2) there have been isolated in pure culture two denitrifying organisms by Burri, and Stutzer, one capable of reducing nitrates when growing alone, and the other capable of this only when growing together with *Bacterium coli* or other members of the coli group. "In com-

(1) Bul. 95, Ind. Agrl. Exp. Sta.

(2) A Review of Investigations in Soil Bacteriology, Bul. 194, Office of Exp. Stations. October 1907. E. B. Voorhees and J. G. Lipman.

municating the results of their experiments they state that there are but a limited number of organisms capable of oxidizing nitrogen, while of those possessing the power of deoxidation (reduction) the number is great. Of these however, the greater part can only reduce nitrates to nitrites and the bacteria capable of reducing nitrates to ammonia, or of setting nitrogen free are not very numerous".

According to Voorhess (1) it has been amply demonstrated that there is little danger of extensive losses of nitrogen in practical agriculture from the complete reduction of nitrates. Where such losses do occur they follow the excessive application of organic manure, or other soil condition that may be justly designated as abnormal.

From the foregoing it is evident that (1) the kind and number of bacteria largely determined the supply of nitrogen which crops are to obtain from the humus in the soil, (2) that the humus must be furnished in sufficient quantities for these organisms to work with, in order to produce enough nitrogen for the growing crop, (3) that bacteria requires certain amounts of mineral substances to carry out the processes which render nitrogen available, (4) that the physical condition of the soil shall be such that it will be a suitable media for the bacteria of nitrification to secure the best results.

(1) New Jersey Station Reports, 1899, p. 97. 1900, p. 88.
1901, p. 144. 1902, p. 133. 1903, p. 148. 1904, p. 191.

Chapter III. A REVIEW OF THE MORE RECENT INVESTIGATIONS WHICH SHOW THE SOURCES OF LOSS OF HUMUS, AND THE MORE PRACTICAL METHODS OF RESTORING IT.

The fact that there has always been new lands to cultivate when the old lands had been cropped to the one crop which gave the greatest immediate return has led to a very exhaustive system of agriculture in America. The land has been cropped until in many places the humus has been almost completely burned out, and therefore the soil is little better than worthless. But the time has now come when there must be an improvement in the systems of agriculture practiced in this country. Some soils are naturally deficient in humus, while others in their virgin state had an abundance. The problem before the American farmer today is to build up the humus content of the naturally deficient soils and maintain the natural humus content of those better supplied with humus. A striking case of how the humus in a soil may be depleted is exhibited in a sample of the more rolling phase of the level prairie silt loam lands in northeast Missouri. The top seven inches of soil taken from a corn field that had been in corn sixteen years, with no application of manure, with the exception of one year when it raised no crop at all, showed a humus content of 2.17 percent, while that of an adjoining field, which had never been

plowed, and represented the virgin state of the corn soil showed a humus percentage of 2.70 percent, a loss of 19.6 percent, or approximately one-fifth of the original supply. Exactly this thing has taken place over wide areas of Missouri's soils with the result that the effect it is now showing strongly in a decreased crop production.

In studying the wheat soils of Minnesota, Snyder (1) has obtained some very striking results. There were six plats used in the experiment. The first year all of the plats were sown to wheat, in order to determine whether the plats were of uniform crop producing power. They were found to be quite uniform, the greatest difference in the yield per acre being 1.1 bushels. Samples were taken of each plat at the beginning of the experiment, and at the end of four years. The system of cropping followed and the nitrogen content are given in the following table:

Plat No.	Cropping	Nitrogen at begin- ning	Nitrogen at end of four years	Gain - Loss -
1	Wheat continuously	.221	.193	-.028
2	Rotation	.221	.231	+.010
3	Rotation	.211	.218	+.0069
4	Corn continuously	.211	.197	-.014
5	Oats continuously	- - -	---	----
6.	Barley continuously	.211	.177	-.034

(1) Bul 53, Minn Agrl. Exp. Sta.
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The rotation followed on plat 2 was clover one year, wheat one year, oats one year. On plant 3, it was oats, with which clover was sown, one year, clover one year, barley one year, corn with 1200 pounds of manure one year. On plat 5 oats were raised continuously, but no figures are given as to the percentage of nitrogen, although the statement is made that during the four years there was an annual loss of 196 pounds.

The humus and volatile matter were also determined with the results stated below:

Plat No.	Humus Per cent	Gain- Loss- Per cent	Total volatile Per cent	Gain+ Loss- Per cent
1	3.00	-.30	7.48	-.20
2	3.80	+.50	8.05	+.37
3	3.50	+.20	7.83	+.15
4	3.10	-.20	7.26	-.42
5	3.08	-.22	7.04	-.54
6	3.10	-.20	6.87	-.81

These figures clearly indicate that continuous cropping rapidly depletes the humus content of our soils. It is remarkable that so great a loss of humus and nitrogen could occur in so short a period of time.

It is observed that for every pound of nitrogen removed by the wheat crop, where it was raised continuously, there has been a loss of five pounds of nitrogen from the soil. Where a rotation was followed there has been an increase of 245 pounds of nitrogen per acre 9 inches, in addition to the nitrogen removed by the crops, attributed to the assimilation of the free nitrogen of the air by clover bacteria. It was also found that continuous cropping with corn did not reduce the nitrogen content as much as did continuous wheat, and the loss from continuous barley and oats was considerably more than wheat.

Frear and Hess (1) in their work at the Pennsylvania Station carried on some experiments for a number of years to determine the effect of various fertilizer treatments upon the organic matter and nitrogen of the soil. The table below gives a statement of some of their results:

Treatment	Organic matter computed from organic carbon	Active humus (matiere noire)	Nitrogen	Ratio nitrogen to humus
Unfertilized	2.85	2.13	.1244	1:17.1
Yard manure	3.26	2.49	.1508	1:16.5
Yard manure and lime	3.09	2.05	.1468	1:14.0
Complete fertilizer, nitrogen applied as nitrate	2.95	2.17	.1378	1:15.7
Complete fertilizer, nitrogen applied as ammonia.	3.02	2.45	.1380	1:17.7

(1) Reprt Pa. Agr. Exp. Sta, 1901.

The results secured show that nearly twenty years of fertilizing by biennial applications of barnyard manure in which about 534 pounds of nitrogen were contained, has resulted in an increase, relative to land cropped identically but receiving no manure, of 522 pounds of nitrogen. The relative increase was only about four-fifths as great when lime was applied with the manure. In the case of the land receiving complete mineral fertilizer containing dung during the period under discussion and equivalent to 684 pounds of nitrogen, the relative increase was only about 260 pounds of nitrogen.

These experiments show little difference in the proportions between the nitrogen and the organic matter on the several manured plats, except that the lime has shown a tendency to cause a more rapid loss of the organic matter than of the manure it accompanies. Where no manure is used the residual carbon is greater than the residual nitrogen, as compared with fertilized lands. The use of mineral fertilizers with and without nitrogen was attended by an increase of carbon relative to nitrogen. This was more pronounced when yard manure was applied.

At the Indiana Station Latta (1) carried on an experiment as to the efficiency of various methods of restoring humus to a soil, which had its humus supply reduced by growing corn and entirely removing the crop for ten successive years.

The methods of restoring humus consisted in (1) passing the corn stover through a feed cutter and restoring it to the soil at the time of plowing, (2) applying wheat straw equal in weight to the stover produced, and (3) sowing crimson clover in the fall to be turned under the following spring. Taking the yields obtained on the plots during the three years preceding these experiments as a base, the stover, wheat straw, and crimson clover increased the production during the last three years of this test by 39.78, 18.19, 17.92 percent, respectively, as compared with the yields of the check plots.

Some very valuable work has been carried on at Grignon in France, by P. P. Dehérain on the various phases of the nitrogen problem, among other phases of the work, that of various fertilizer systems and cropping systems upon the carbon and nitrogen in the soil. A table showing some of the more important results obtained in these experiments is given below, taken from an editorial by Emile Demoussy.(2)

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- (1) Ind. Agr. Station Report, 1901. pages 22-5
 - (2) Exp. Sta. Rec. Vol. V, page 18.

Plats	Nitrogen per kilo of soil			Carbon per kilo of soil			Ration N to C.	
	1878	1888	Dif.	1878	1888	Dif.	1878	1888
	gm.	gm.	gm.	gm.	gm.	gm.		
Constantly unmanured	1.67	1.48	.19	15.19	7.30	7.89	1:9.0	1:4.9
" "	1.74	1.50	.24	16.30	7.30	9.00	1:9.3	1:4.8
Regularly manured	2.00	1.90	.10	15.20	16.10	-.90	1:7.6	1:8.4
" "	2.00	1.86	.14	16.60	16.00	-.60	1:8.3	1:8.5

The more interesting features of this table are the differences in the loss of nitrogen sustained by the manured and unmanured plats in favor of the manured plats, and more striking still are the differences in the amount of carbon, in one case there being a gain of carbon indicating an increase in the amount of humus. These experiments indicate that the application of manure increases the carbon content more rapidly proportionately than it does the nitrogen.

In investigating the soils of the United States by means of the paraffine wire basket method, Gardener (1) has obtained some very interesting results. The soils tested, 220 in number, representing ninety types, half that number of series, and many geological formations. They were taken in twenty-three states extending from the Mississippi valley to the Atlantic sea board, and from Rhode Island to Texas.

(1) Bul. 48, Bureau of Soils, U. S. D. A.

One of the most important of their conclusions in this work is summed up as follows: "As an average of all tests, the organic manures have outranked the chemical ones. Barnyard manure and cowpeas vines with lime tie for first rank. The three chemical salts with lime ranked third, and the same salts without lime ranked fourth."

In studying some of the soils of Missouri the following results were secured by the Bureau of Soils by the wire basket method:

Location	Weight of plants grown on untreat- ed soil.	Gain or Loss attributable to -										
		P	K	N	PK	PN	KN	PKN	L	PK NL	M	CVL
Crawford County Clarksv'e silt loam	6.6	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc
		26	15	17	27	25	15	17	14	1	43	32
Wabash silt loam	7.6	-11	1	-3	-2	3	-5	-1	0	2	23	24
Clarksv'e stony loam	14.6	4	3	-2	-9	2	11	3	-3	-2	-10	13
Avg. for Co.	9.6	6	6	4	5	10	7	3	4	0	19	23
Scotland Co. Shelby silt loam	9.6	7	24	14	22	17	32	28	11	28	69	30
Boone Co. loess- McBaine Silt loam	7.8	8	22	28	26	26	47	50	19	--	23	35
Columbia	5.9	--	--	--	29	54	44	61	7	66	34	50
Dent Co. Salem clay loam	7.0	--	--	--	25	50	60	68	25	50	57	35

The symbols at the head of the columns stand for the following treatments: P stands for acid phosphate; K for sulphate of potash; N for nitrate of soda; L for air-slaked lime; M for well rotted stable manure and CV for green cowpea vines.

This table shows that with very few exceptions farm manure and cowpea vines gave the best results. The soils tested represent very important soil types in Missouri, the samples from Crawford County representing a large area of the Ozark soils, the silt loam from Scotland County, a large part of the prairie lands of northeast Missouri, the loess, from McBaine, the extensive loess deposits occurring along the Missouri River, the silt loam from Columbia, the broken areas lying farther back from the Missouri River than the loess deposits, and the clay loam from Salem, another phase of the soils of the Ozark region.

It has also been shown by the results obtained from the outlying fields under the supervision of the Missouri Experiment Station, eighteen in number, located in agriculturally important parts of the State, that manure and cowpeas ^(where the soil has become adjusted to them) give better results than any other treatment.

From the foregoing it will be seen that continuous cropping of land without the use of humus supplying manures results in both the depletion of the humus and nitrogen, besides injuring the physical properties of the soil and decreasing the crop yield. It has also been shown that

barnyard manure, one of the waste products of the farm, and the growing of legumes which appropriate large amounts of nitrogen from the atmosphere, together with a systematic rotation of crops are the most effective, as well as practical, methods of maintaining the humus supply of soils. ✓

Chapter IV. RESULTS OF EXPERIMENTS WITH MISSOURI SOILS.

The soils of Missouri, with very few exception, are deficient in humus, and the continuous cropping (to corn especially) which is practiced in many parts of the State is rapidly depleting what humus there is in the soil. In many parts of the State the crop yields are rapidly decreasing as a result of this, while in other localities it is not as yet evidenced in the crop yields to a perceptible degree, but in either case it demands attention, for it is much easier to maintain a natural humus supply than it is to build one up, and in the case of the lands where it is now effecting the crop yield it must be built up or the land will soon fail to produce a remunerative crop.

In order to study the effect of various crop rotations and fertilizer treatments upon the humus content of Missouri soils two lines of experiment were carried out. First, a study of the effect of crop rotation and manures upon the humus and nitrogen content of soils as evidenced in the rotation plats of the Missouri Experiment Station. And second, a study of the needs of organic matter of some of the more important soils of the State by means of the paraffine wire basket method.

The Effect of crop rotation and the use of Manures upon the Nitrogen and Humus content of the Soil.

In order to determine the value of various crop rotations, the Missouri Experiment Station laid out in 1888 thirty-nine plats on which various crop rotations and systems of manuring were practiced. At this time the plats were one-thneth acre in size and remained so until 1904, when a street was laid out on one side thereby reducing the size of some of the plats, and in order to make all of a uniform size they were reduced to one-thirteenth acre.

The treatment of the plats was as follows:

- Plat 1 Six year rotation; wheat, timothy, timothy, corn, oats and clover; 1400 pounds yard manure.
- Plat 2 Wheat continuously; chemicals for 40 bushels of wheat applied according to rate in wheat and straw.
- Plat 3 Six year rotation; Wheat, timothy, timothy, corn, oats and clover; chemicals for full crop used according to analysis of each crop, i. e., for 40 bushels of wheat, 80 bushels of corn, 60 bushels of oats and three tons of hay and clover.
- # Plat 4 Six year rotation; Wheat, timothy, timothy, corn, oats, and clover; 600 pounds yard manure, and one-half ration chemicals.
- Plat 5 Wheat continuously; 1200 pounds yard manure.

Not used in humus and nitrogen studies.

- #Plat 6 Clover continuously; 1200 pounds yard manure.
- #Plat 7 Clover continuously; no manure.
- #Plat 8 Six year rotation; clover, wheat, timothy, timothy,
corn and oats; 1200 lbs yard manure.
- Plat 9 Wheat continuously; no manure.
- Plat 10 Wheat continuous; 1200 pounds yard manure.
- Plat 11 Six year rotation (as above); 1200 pounds yard manure.
- #Plat 12 Six year rotation (as above); no manure.
- Plat 13 Six year rotation (as above); no manure.
- #Plat 14 Six year rotation (as above); 1200 pounds yard manure.
- Plat 15 Oats continuously; 1200 pounds yard manure.
- Plat 16 Oats continuously; no manure.
- Plat 17 Corn continuously; no manure.
- Plat 18 Corn continuously; 1200 pounds yard manure.
- #Plat 19 Six year rotation (as above); 1200 pounds yard manure.
- #Plat 20 Six year rotation (as above); 1200 pounds yard manure.
- #Plat 21 Wheat continuously; 1200 pounds yard manure.
- Plat 22 Timothy continuously; 1200 pounds yard manure.
- Plat 23 Timothy continuously; no manure.
- #Plat 24 Wheat continuously; 1200 pounds yard manure.
- #Plat 25 Three year rotation; corn, clover, and wheat;
1200 pounds yard manure.
- Plat 26 Three year rotation (as above); 1200 pounds yard manure.
- Plat 27 Three year rotation (as above); no manure.
- #Plat 28 Three year rotation (as above); 1200 pounds yard manure.

No used in humus and nitrogen studies.

- Plat 29 Wheat continuously; no manure.
- Plat 30 Wheat continuously; 1200 pounds yard manure.
- Plat 31 Two year rotation; wheat and clover; 1200 lbs. yard manure.
- #Plat 32 Two year rotation (as above); 1200 lbs. yard manure.
- Plat 33 Two year rotation (as above); no manure.
- #Plat 34 Four year rotation; corn, oats, clover, and wheat; 1200 lbs. yard manure.
- #Plat 35 Four year rotation (as above); 1200 lbs. yard manure.
- #Plat 36 Wheat continuously; 1200 lbs. yard manure.
- #Plat 37 Four year rotation (as above); 1200 lbs. yard manure.
- Plat 38 Four year rotation (as above); 1200 lbs. yard manure.
- Plat 39 Four year rotation (as above); no manure.

The treatment of some of the plats has been slightly modified from the original plan, but the greater part of them have been carried out as outlined. In studying the humus and nitrogen content of these plats only those on which the original system has been carried out are considered.

On December 20~~th~~ to 23, 1906, nearly eighteen years after the beginning of the experiment, samples were taken from the plats indicated in the diagram below. The samples were taken with a two inch auger, four borings being made in each plat. The samples were taken in three sections, e. g., the top seven inches from seven to eighteen inches; and from eighteen to forty inches.

Not used in humus and nitrogen studies.

The diagram below shows the arrangement of the plats described in the preceding pages, the ones sampled being indicated.

			#		#	#	#
8	7	6	5	4	3	2	1
9	#			17	#		
10	#			18	#		
11	#			19			
12	#			20			
13	#			21			
14	#			22	#		
15	#			23	#		
16	#			24			
29	#			25			
30	#			26	#		
31	#			27	#		
32				28			
33	#						
34							
35							
36							
37							
38	#						
39	#

After being thoroughly air dried and pulverized fine enough to pass through a 2 mm sieve the soil~~s~~ was thoroughly mixed and put in one quart, screw top glass jars.

As we have no record of determination of humus and nitrogen when the experiment began, samples were taken from various points in the driveway between the plats, which had not been plowed in the meantime, and supports a heavy growth of bluegrass. Determinations of humus and nitrogen ~~were~~ made of these, however, are not a fair representative of the soil at the beginning, and can only be considered as approximations to the conditions existing at that time.

The volatile matter was determined by drying in an oven at about 100 C and then ignited before a glass lamp, a 2 gram sample being used, the difference in the weights before and after ignitions representing the total volatile matter.

There have been numerous methods suggested for the estimation of humus in soils. Th two methods which are used most at the present time are the combustion method and humus extraction mthod. The combustion method is based on the oxidation of the organic matter, either in a tube in a furnace, or by powerful oxidizing agents, such as chromic acid or potassium permanganate and collecting and determining the carbon dioxide liberated. From this the carbon is calculated, which in turn is converted into humus by the use of a factor (the percentage of carbon in humus is from less than forty percent to more than sixty percent). The mothod

which the Bureau of Soils and some of the Experiment Stations are using as described by Cameron and Breazealle (1) is a modification of this method. It is said to be quite rapid, a determination requiring on the average, about forty minutes. The principle objection to the method is the fact that the proportion of carbon to humus is not constant, hence the humus determined in this way may be too high or too low, depending upon the proportion of carbon to humus.

The official method of the American Association of Agricultural Chemists consists in extracting the humus with a four percent of ammonium hydroxid solution, after washing the soil with a one percent hydrochloric acid solution, then evaporating the solution to dryness, after which it is ignited, the loss on ignition being the humus. This method was used in the humus determinations which were made in this work. The method in detail is as follows: (2) "Place ten grams of the sample in gooch crucible, extract with 1 percent hydrochloric acid until the filtrate gives no precipitate with ammonium hydroxid and ammonium oxalate, and remove the acid by washing with water. Wash the contents of the crucible (including the asbestos filter) into a glass stoppered cylinder, with 500 cc of 4 percent ammonium hydroxid, and allow to remain with occasional shaking for twenty-four hours. During this time the cylinder is inclined as much as possible without

(1) Jour. Amer. Chem. Soc. Vol XXVI, No. 1. and Bul. 24, Bureau of Soils, U. S. D. A.

(2) Bul. 107, Bureau of Chem., U. S. D. A.

bringing the contents in contact with the stopper, thus allowing the soil to settle on the side of the cylinder and exposing a very large surface to the action of the ammonium hydroxide. Place the cylinder in a vertical position, and leave for twelve hours, to allow the sediment to settle. Filter the super-natant liquid (filtrate must be perfectly clear), evaporate in aliquot, dry 100 °C and weight. Then ignite the residue and again weigh. Calculate the humus from the difference in weight between the dried and ignited residues".

The nitrogen determinations were made according to the Kjeldahl method, a 10 gram sample being used. Determinations were made in duplicate of the first and second borings of each plat.

The table below gives the results of the analyses:

Plat	Fertilizer treatment	Cropping	Volatile matter	Humus	Nitrogen 0-7 in.	Nitrogen 7-18 in.	Pounds nitrogen in acre 7 in.
			Percent	P. ct.	Percent	Percent	
I	1400 lbs M	6yr. rotation	5.75	2.17	0.235	0.096	4700
2	Chem 40 bu	Wheat	5.15	1.40	.210	.154	4200
3	" full crop	6yr r'ttn	5.60	2.12	.145	.159	2900
4	1200 lbs M	Wheat	6.25	1.66	.155	.084	3100
9	nothing	Wheat	4.95	1.52	.149	.080	2980
10	1200 lbs M	Wheat	6.60	2.05	.208	.110	4160
11	1200 lbs M	6yr r'ttn	6.50	2.23	.195	.106	3900
12	1200 lbs M	6yr r'ttn	5.80	1.75	.180	.097	3600
13	nothing	6yr r'ttn	4.85	1.90	.146	.082	2960
14	1200 lbs M	6yr r'ttn	4.75	2.07	.172	.089	3440
15	1200 lbs M	Oats	5.45	1.94	.200	.101	4000
16	nothing	Oats	4.20	1.90	.128	.070	2560
17	nothing	Corn	4.00	1.47	.101	.078	2020
18	1200 lbs M	Corn	5.15	1.87	.162	.088	3240
22	1200 lbs M	Timothy	5.15	1.70	.168	.090	3360
23	nothing	Timothy	5.05	1.80	.155	.087	3100
26	1200 lbs M	3yr r'ttn	5.50	1.70	.169	.097	3380
27	nothing	3yr r'ttn	4.50	1.26	.130	.080	2600
29	nothing	Wheat	5.30	1.80	.150	.091	3000
30	1200 lbs M	Wheat	5.55	2.00	.182	.090	3640
31	1200 lbs M	2 yr r'ttn	5.65	2.00	.210	.105	4200
33	nothing	2 yr r'ttn	5.05	2.00	.157	.097	3140
38	1200 lbs M	4yr r'ttn	5.00	1.95	.165	.092	3300
39	nothing	4 yr r'ttn	4.15	1.07	.145	.091	2900
Bluegrass sod from driveway							
		Comp. A	5.55	1.90	.174	.077	3480
		Comp. B	5.65	2.40	.150	.081	3000

In considering the results of this work we must consider that the humus content and nitrogen supply of the plots was practically uniform at the beginning of the experiment. This was no doubt true as plots with the same treatment in different parts of the field show about the same percentages of humus and nitrogen.

The most striking figures in the above table are the relatively small amounts of humus and nitrogen in the plat continuously cropped with corn. Its nitrogen content is lower than that of any of the other plats, and the percentage of humus is below the average. The total volatile matter is also lower than that of any other plat. This can probably be explained by the fact that corn removes a larger amount of nitrogen than the other crops and that the soil is kept favorable for the process of decomposition during a longer period than it is in case of the other crops. Nitratification takes place only during the warmer months and this is the period when the soil in continuous corn culture is kept loose and has a fair degree of moisture, thus supplying the ideal conditions for the oxidation of organic matter, in most cases faster than the plant is able to feed on the nitrogen which it supplies and hence some of the nitrogen is lost by the volatilization of nitrogen as ammonia or free nitrogen.

Next to the corn plat the oat plat showed the lowest nitrogen content, and with one exception the lowest as to total volatile matter, although the humus content was relatively high, as with continuous corn culture the constant cropping which subjects the soil to the most favorable conditions for nitrification, may account in part for the rapid decrease in the percentage of total nitrogen. The remarkable figures for this plat is the relatively high percent of humus.

ROTATION SERIES

Chart showing percentages of volatile matter, humus and nitrogen in plats receiving various treatments

Top 7 inches of soil

Wheat continuously-No manure

Wheat continuously-1200 lbs manure

Wheat continuously-chemicals for 40 bu.

Oats continuously-no manure

Oats continuously-1200 lbs manure

Corn continuously-no manure

Corn continuously-1200 lbs manure

Timothy continuously-no manure

Timothy continuously-1200 lbs manure

Wheat and clover rotation-no manure

Wheat and clover rotation-1200 lbs manure

Corn wheat and clover rotation-no manure

Corn wheat and clover rotation-1200 lbs manure

Six year rotation-no manure

Six year rotation-1200 lbs manure

Six year rotation-1400 lbs manure

Six year rotation-chemicals for full crop

Volatile matter

Humus

Nitrogen

ROTATION SERIES

Chart showing the relative amounts of
nitrogen in plats receiving
various treatments
Top 7 inches of soil

Wheat continuously-No manure

Wheat continuously-1200 lbs manure

Wheat continuously-chemicals for 40 bu.

Oats continuously-No manure

Oats continuously-1200 lbs manure

Corn continuously-No manure

Corn continuously-1200 lbs. manure

Timothy continuously-No manure

Timothy continuously-1200 lbs manure

Wheat and Clover rotation-No manure

Wheat and Clover rotation-1200 lbs manure

Corn, Wheat and Clover rotation-No manure

Corn, Wheat and Clover rotation-1200 lbs. manure

Six year rotation-No manure

Six year rotation-1200 lbs manure

Six year rotation-1400 lbs manure

Six year rotation-chemicals for full crop

ROTATION SERIES

Chart showing relative amounts of humus in
unmanured plats with various systems of cropping
Wheat continuously Top 7 inches of soil

Oats continuously

Corn continuously

Timothy continuously

Wheat and clover rotation

Corn, wheat, and clover rotation

Six year rotation-wheat, timothy, timothy, corn, oats, clover

ROTATION SERIES

Chart showing relative amounts of nitrogen in
unmanured plats with various systems of cropping
Wheat continuously Top 7 inches of soil

Oats continuously

Corn continuously

Timothy continuously

Wheat and clover rotation

Corn, wheat and clover rotation

Six year rotation - wheat, timothy, timothy, corn, oats, clover

The figures obtained on the wheat plats are also remarkable. The humus in this case is lower where continuous wheat culture was followed, but the nitrogen is somewhat greater than it is in the case of the six year rotation, with no manure. The total volatile matter is also lower in the rotated plat.

Continuous timothy showed an increase of nitrogen, humus, and total volatile matter over that of the six year rotation plat, and manuring did not seem to increase the humus content although the nitrogen of the manured timothy plat was considerable greater than that of the unmanured one.

In considering the rotations, the humus content of the plats on which the two year rotation was followed ranked first, without manure. This can possibly be explained by the fact that clover was grown one year, and contrary to Snyder's results wheat has also been shown to be less exhaustive than corn or oats, and when these are left out of the rotation the conditions are more favorable for maintaining the humus and nitrogen supply. The percentage of total volatile matter, humus and nitrogen, were all greater in this plat than any of the other rotated plats without manure.

Ranking next to the two year rotation, the six year rotation plat, without manure, showed the highest percentage of total volatile matter, humus and nitrogen. The only explanation for this is that three out of the six years the plat was growing a crop which did not deplete the humus supply.

Two years it was in timothy, which judging from the plat which grew timothy continuously, does not exhaust, and if anything builds up the humus supply, and one year it was in clover, which is a humus forming crop;

The three year rotation ranks third in the percentage of volatile matter and humus, although the nitrogen is slightly lower than in the plat on which the four year rotation is followed. Oats, one of the humus destroying crops, is taken from a four year rotation in making a three year rotation, which in part at least may account for the higher percentage of humus in the three year plat.

The four year rotation plat, without manure, showed the lowest percentage of volatile matter and humus, and next to the lowest nitrogen content of any of the rotation plats. Judging from the results obtained from the plats on which corn and oats were grown continuously, this is what we might expect. In this rotation these two crops occupy the ground one half of the time, which is proportionately greater than is true of any of the other rotations.

Without exception the application of manure caused an increase of either the humus or the nitrogen content, and with one or two exception it increased both. The highest humus and nitrogen content was in the case of plat 1, where 1400 lbs. of manure were used with a six year rotation. The highest humus and nitrogen content of any plat cropped continuously with an application of manure, was in the case of

plat ten, which was cropped with wheat with an application of 1200 pounds of manure.

Another remarkable feature is the relatively high percent of humus in the plats on which mineral fertilizers were applied. The humus content of plat two on which wheat was grown continuously, with an adequate amount of mineral plant food it is by no means the lowest, and that of plat three, on which a six year rotation was followed, and mineral plant food added for full crop, the humus content was third highest of any of the plats.

Contrary to the results obtained by Snyder corn grown continuously produced a greater decrease both in nitrogen and humus than did wheat. Oats caused a more rapid decrease than did wheat, which is in accordance with his results. But they also caused a less decrease than corn which is contrary to them. The magnitude of the difference of the results obtained in these experiments is much less than he secured, although the period which the cropping systems covered was nearly five times as long.

The results obtained accord with the results secured at the Pennsylvania Station as to the effect of manure on the humus and nitrogen content of the soil. The period covered by the experiment there was twenty years and the results on the unmanured and manured plats are quite comparable to those secured on similarly treated plats used in this experiment.

Pot Experiments on Certain Missouri Soils.

In order to compare the effect of varying forms and amount of different sorts of organic matter upon the more important Missouri soils, some experiments with the paraffine wire basket method of pot culture were carried out.

This method has the advantage over ordinary pot culture in that the moisture condition of the soil can be controlled absolutely and a record of the transpirations of each plant kept. By making the pots large enough some of the more important agricultural plants can be grown to maturity. Tacking the total transpiration and the mature weight of the plant into consideration by comparison with a check pot we have a fairly reliable index as to the value of any fertilizer treatment which may have been used.

The pots used in these experiments were made by cutting galvanized wire netting, of the one-fourth inch mesh, into strips 17 inches long and 7 1/2 inches wide, after which it was rolled into a cylinder, two meshes being turned in at one end which support a disk 5 inches in diameter forming the bottom of the pot. The pots are held together by three copper rivets, one at the top, one at the bottom and one in the middle, care being taken that there shall be two meshes between the rivet and the edge of the netting.

The next step is to cover the top half of the pot with a coat of paraffine. This is done by dipping it in a vessel of melted paraffine several times in succession allowing it to cool each time before returning it to the melted

paraffine. This can be effected by dipping in paraffine and cold water alternately. This should be done until the upper half of the basket is covered with a continuous coat of paraffine. The paraffine should be of a high melting point, as that with a low point has been found to melt under greenhouse conditions. The pot is now ready for the soil.

The soil of each pot in a series should have a uniform moisture content, this being accomplished by taking an amount of soil adequate for the entire series and adding water until the optimum ~~water~~ moisture content is uniform throughout. From this stock soil each pot can be filled and the fertilizer treatment applied. The optimum moisture content is secured by adding water enough so that the soil contains all that it can hold as capillary water. This is best accomplished by adding the water to the soil several hours in advance of the time it is to be placed in the pots, thus allowing it to be uniformly distributed by capillarity.

The pots are next filled to within one inch from the top ~~of~~ with the soil to which the respective treatments have been applied, and the lower half of the pot dipped in melted paraffine forming a coat continuous with that of the upper half. The seeds (which have been germinated a day or two in advance) are then planted, five or six seedlings

being placed in each pot. The pots are now weighed and a record kept of the weight of each. A layer of sand about 1/2 inch in thickness is then put over the soil and the pot again weighed.

After the plants are all about one or two inches above the surface of the sand the pots are again weighed and the loss in weight sustained by evaporation recorded and the original water content restored by adding water until the original weight of the pot is obtained. The surface of the soil is now covered with a disk of ~~the~~ paraffine paper (a slit being cut through which the plants may grow) and the edges sealed to the sides of the pot by means of melted paraffine. This prevents any loss of the soil moisture, except through the plant by transpiration. A record of the transpiration is kept by weighing the pots about every three or four days and restoring the original moisture content to each pot.

In these experiments "Texas Red Rust Proof" oats were grown. They were grown to maturity in about three months. Five soils were used, representing wide variations as to their character. The manure used was horse manure mixed with wheat straw. It was dried and thoroughly pulverized by running through a meat chopper. The figures given, (3, 6, and 9 tons per acre) are for the dry weight of the manure, which when account is taken of the moisture content (usually about 75%) would be 12, 24, and 36 tons per acre, respectively.

The rock phosphate used was finely pulverized Tennessee Phosphate Rock, yielding about 30 percent of phosphoric acid. It was applied at the rate of 1000 pounds per acre.

The lime was applied in the form of ground limestone at the rate of 1 ton per acre.

The green manure was green clover which was applied at the rate of 8 tons per acre.

The results obtained on each soil are considered in detail below:

STATION SOIL.

The soil was taken from the Experiment Station farm and is a fair representative of the broken land which lies farther back from the Missouri River than the loess soils, and is really a phase of the north Missouri prairie considerably eroded. It is similar to the soil on the rotation plats which have been studied in the foregoing pages, the total volatile matter being between four and five percent and the humus 1.5 to 2 percent. In texture it is a silt loam with a rather stiff tenaceous clay subsoil. The soil ~~was~~ used in this work was taken from the top seven inches.

The pots were planted March 29th and on April 8th they were sealed, after which time the record for the total transpiration is figured. They were weighed at intervals of four or five days until July 16th, when the mature plants were harvested and weighed. The results obtained are as follows:

Pot No.	Treatment	Dry Wt. of mature plant	Total transpiration.	Gain attributable to treatment.	
				Dry Wt.	Trans.
		Kilos.	Kilos.	Per ct.	Per ct.
1	Check	1.97	1.898	----	-----
2	Manure 3T per A	2.71	2.351	37.2	23.8
3	Manure 6T per A	3.55	3.255	80.2	71.5
4	Manure 3T, Rock Phos	2.49	2.780	26.4	46.6
5	Manure 3T, Lime	2.46	2.902	29.9	52.8
6	Manure, Rock Phos. and lime.	2.70	2.920	37.0	53.8
7	Green manure	3.20	3.606	62.4	89.9

It will be noticed that the manure gave a marked increase in the total transpiration over the unmanured pot. The increase was still greater when the amount of manure was doubled the percent of increase was also doubled.

The pot which received the green manure treatment showed a still greater increase in the total transpiration but the dry weight of the mature plant was slightly lower than that of the pot receiving six tons of manure per acre.

PLATE V.

Station Soil.

Photographed June 1st.

1. Check.
2. Manure - 3 tone per acre.
3. Manure - 6 tons per acre.
4. Manure - 3 tons per acre + rock phosphate.
5. Manure - 3 tons per acre + CaCO_3 .
6. Manure - 3 tons per acre + rock phosphate + CaCO_3 .
7. Green clover. (turned under)

STATION SOIL

Chart showing total transpiration and wt. of the mature plant with various treatments

Check- No treatment

Manure-3 tons per acre

Manure-6 tons per acre

Manure-3 tons per acre + Rock Phos.

Manure-3 tons per acre + CaCO_3

Manure-3 tons per acre + Rock Phos. + CaCO_3

Green clover (turned under)

Total transpiration Dry wt. of mature plant

The addition of rock phosphate to the manure treatment gave an increase in transpiration over the application of manure alone, but the increase was not equal to that secured by the application of six tons of manure. The dry weight of the plant was, however, slightly lower than in the pot which received manure alone.

Lime with manure increased the transpiration still more than rock phosphate, but the weight of the plant was slightly less. Lime, with manure and rock phosphate showed a still greater increase in transpiration, while the dry weight of the plant was practically the same when manure was used alone.

A remarkable feature of this series is the fact that in case where the mineral fertilizers were added and also green manure, the dry weight is less than the transpiration. This may probably have been due to ^{differences in} physical ~~condition~~ condition together with the unavailable form of the lime and rock phosphate which would cause a greater transpiration of a less dense soil solution.

Poplar Bluff Soil.

This soil was taken from the lowland region in the neighborhood of Poplar Bluff, and represents a large area of the lowlands of southeast Missouri. It is a gray, or nearly white silt loam and exceedingly low in humus, having been subject to "swamping", causing a leaching brought about by an accumulation of organic acids. The total volatile matter in the

soil is 3.30 percent. These soils however, are as yet fairly productive as they have been cultivated only a short time, but the humus supply must be built up for the supply of nitrogen in the future.

The pots in the test were planted March 26th, and on April 1st they were sealed, after which time the total transpiration is figured. They were weighed at intervals of from four or five days until July 16th when the mature plants were harvested and weighed. The results are as follows:

Pot No.	Treatment	Dry Wt. of mature plant	Total Trans.	Gain or loss attributable to treatment.	
		Kilos.	Kilos	Dry Wt.	Trans.
1.	Check	2.77	2.815	----	----
2.	Manure 3T per A	4.25	3.399	53.4	20.3
3.	Manure 6T per A	4.09	3.003	47.6	6.6
4.	Manure 9T per A	3.85	3.148	38.9	11.8
5.	Manure 3T, Rock Phos	3.70	3.063	33.5	8.8
6.	Manure 3T, Lime	3.99	3.399	44.0	20.3
7.	Manure 3T, Rock Phos., Lime	4.45	3.276	60.6	16.0
8.	Green manure	4.90	3.364	76.8	19.5

In the pot receiving 3 tons of manure per acre there is a remarkable increase in the transpiration and dry weight, but when the amount was increased to 6 tons, while there was still an increase over the check ~~pot~~ pot there was a

PLATE VII.

POPLAR BLUFF SOIL.

Photographed June 1st.

1. Check.
2. Manure - 3 tons per acre.
3. Manure - 6 tons per acre.
4. Manure - 9 tons per acre.
5. Manure - 3 tons per acre + rock phosphate.
6. Manure - 3 tons per acre + CaCO_3 .
7. Manure - 3 tons per acre + rock phosphate + CaCO_3 .
8. Green Clover. (turned under)

POPLAR BLUFF SOIL

Chart showing total transpiration and dry wt of mature plant with various treatments

Total transpiration

Dry wt of mature plant

marked decrease in both transpiration and weight. 9 tons reduced the dry weight still lower than 6 tons, but the transpiration was slightly greater.

Both rock phosphate and lime, when added to the manure treatment singly, decreased the transpiration and dry weight but when used in combination they increased the dry weight but the transpiration was still less than when manure was used alone.

The pot to which green manure was added produced a higher dry weight than any pot in the series, but the transpiration was slightly less than pots two and six.

A possible explanation of the decrease in yield with an increase in the amount of manure applied, may be that the soil is fairly fertile and slightly acid, hence an excess of manure could not increase the fertility, and in addition might increase the acidity. This is corroborated by the fact that lime and rock phosphate caused a slight increase, which may be attributed to their neutralizing effect on the acidity.

Victoria Soil.

This soil was obtained from Victoria, in Jefferson County, and represents a considerable area of that part of the State. It is a reddish yellow silt loam, formed from the Trenton limestone. The total volatile matter is 2.8 percent. This soil is a fairly good soil, but is markedly deficient in humus. By increasing the humus supply it could be made to be one of the most productive soils south of the River.

PLATE LX.

Victoria Soil.

Photographed June 2nd.

1. Check.
2. Manure - 3 tons per acre.
3. Manure - 6 tons per acre.
4. Manure - 9 tons per acre.
5. Manure - 3 tons per acre + rock phosphate.
6. Manure - 3 tons per acre + ground limestone.
7. Manure - 3 tons per acre + rock phosphate and ground lime-
(stone.
8. Green Clover. (Turned under)

The pots in the test were planted March 29th and weighed at intervals until July 16th, when they were harvested and weighed. The results are as follows

Pot No.	Treatment	Dry Wt. of mature plant	Total trans.	Gain attributable to treatment	
		Kilos.	Kilos.	Dry Wt. Per ct.	Trans. Per ct.
1.	Check	2.22	2.342	----	----
2.	Manure 3T per A	3.79	2.727	70.7	16.4
3.	Manure 6T per A	4.20	2.851	89.1	21.7
4.	Manure 9T per A	4.30	3.066	93.6	30.9
5.	Manure 3T, Rock Phos	2.95	2.624	32.8	12.0
6.	Manure 3T, Lime	3.72	2.862	67.5	22.2
7.	Manure 3T, Rock Phos and lime	4.32	2.994	94.5	27.8
8.	Green manure	3.50	2.611	57.6	11.0

The pots which were treated with manure in this series show a marked increase over the unmanured pot, the increase being greater with each increase in the amount of manure added. The increase is shown both in the dry weight and transpiration.

The addition of rock phosphate to the manure treatment caused a decrease both in transpiration and dry weight.

VICTORIA SOIL

Chart showing total transpiration and dry wt. of the mature plant with various treatments

Total transpiration
 Dry wt. of mature plant

The use of lime with the manure produced very little effect but when lime and rock phosphate were used together the weight of the plant exceeded the one which was grown with a treatment of 9 tons of manure, although the transpiration was slightly less.

Green manure for some reason failed to produce a beneficial effect as the treatment with 3 tons of manure, although it produced a marked increase both in transpiration and dry weight over the check plot.

The fact that an increase of manure caused an increase in yield in each case is probably due to the extremely low humus content being increased by the addition of manure. The fact that the soil is fairly well supplied with the mineral elements possibly accounts for the failure to respond to their addition. Lime, when added with rock phosphate may have made it more available.

Dixon Soil.

This soil was taken from a field near Dixon, in Pulaski County, and represents a large area of the Ozark region; being classed as the black oak gravel of the Ozark upland. It is one of the poorer soils in the State, as indicated in the following analysis made in connection with the work of the State Soil Survey.

PLATE ~~XL~~.

Dixon Soil.

Photographed June 1st.

1. Check.
2. Manure - 3 tons per acre.
3. Manure - 6 tons per acre.
4. Manure - 3 tons per acre + rock phosphate.
5. Manure - 3 tons per acre + CaCO_3 .
6. Manure - 3 tons per acre + rock phosphate + CaCO_3 .
7. Green Clover (turned under.)

	Total	P O	K O	Lime	Mag- nesia	Fe & Al oxids	Acid insol- uble	Volatile matter
Soil Percent	.084	.046	.215	.234	256	5.474	90.307	3.585
Pounds per acre	1680	920	4300	4680	5120			
Subsoil Percent	.048	.035	.375	.174	386	9.407	86.133	3.660
Pounds Per acre	960	700	7500	3480	7720			

It will be seen from this that this soil is especially deficient in organic matter, nitrogen and phosphorus. In texture it is a silt loam or silty clay loam.

The pots containing the Dixon soil were planted March 26th, and weighed and watered at intervals as in case of the other series and were harvested and weighed July 16th. The figures given below for the total transpiration take in account only the transpiration from April 1st to June 19th after which time factors entered in which render the results incomparable. The results are as follows:

Pot No.	Treatment	Dry Wt. of mature plant Kilos.	Total trans. Kilos.	Gain or loss attrib- utable to treatment Dry. Wt. Percent	Trans. Percent
1.	Check	0.79	.761	---	---
2.	Manure 3T per A	.95	.621	- 7.5	-18.3
3.	Manure 6T per A	.80	.682	- 1.2	-10.3
4.	Manure 3T, Rock Ph	.77	.657	-3.8	-13.6
5.	Manure 3T, Lime	.78	.790	-2.5	-5.1
6.	Manure 3T, Rock Phos, Lime.	1.48	.830	-87.3	-9.0
7.	Green manure	4.12	2.234	-421.5	-193.5

DIXON SOIL

Chart showing total transpiration and dry wt of mature plant with various treatments

Check No treatment

Manure - 3 tons per acre

Manure - 6 tons per acre

Manure - 3 tons per acre + Rock phosphate

Manure - 3 tons per acre + CaCO_3

Manure - 3 tons per acre + Rock phosphate + CaCO_3

Green clover (turned under)

Total transpiration
 Dry wt. of mature plant

The most striking feature of this table is the extremely low yields and transpiration of all the pots except the one to which green manure had been added.

Manure produced a slight increase in the dry weight, while rock phosphate and lime used singly with manure produced a slight decrease in yield when compared with the check pot. Manure and manure and rock phosphate show a less total transpiration than the check pot and manure and lime produced a slight increase.

As was the case with the Victoria soil, this soil showed an increase in both dry weight and transpiration when lime and rock phosphate were used together while when they were used alone the benefits were not so noticeable. It is more marked in this case however.

Green manure shows by far the best results, it being the only pot in the series that showed any very marked effect of the treatments applied.

The failure of this soil to respond to treatment may have been due to the fact that it is a very unproductive soil and possibly lacks the bacterial flora for the decomposition of organic matter which may not have been supplied in the dry manure, but might have been in the green clover.

Lamar Soil.

This soil is a representative of the level prairie lands of southwest Missouri, taken in the vicinity of Lamer. It is a gray silt loam, and a rather unproductive soil. An analysis made in connection with the work of the State Soil Survey is as follows:

	Total nitrogen	P O	K O	Lime	Magne- sia	Fe & Al oxids	Acid insol- uble	Volatil matter
Soil Percent	.124	.051	.231	.248	.2120	5.672	89.290	4.535
Pounds Per acre	2480	1020	4620	4960	4240	-----	-----	-----
Subsoil Percent	.071	.042	.438	.368	.466	14.642	78.628	5.798
Pounds Per acre	1420	840	8760	7360	9320	-----	-----	-----

This soil, it is evident, is low in all the plant food elements notably nitrogen and phosphorus. The total volatile matter is also quite low.

The pots in this series were planted March 29th, and weighed at intervals as in the other series, and were harvested July 16th. Unfortunately the plants in the check pot were killed by fumigation, but as the series was showing some differences it was thought best to continue it so that we can make comparisons of the effect of each treatment.

The results are as follows:

PLATE ~~XIII~~ .

Lamar Soil.

Photographed June 1st.

1. Check. Plant dead.
2. Manure - 3 tons per acre.
3. Manure - 6 tons per acre.
4. Manure - 3 tons per acre + rock phosphate.
5. Manure - 3 tons per acre + CaCO_3 .
6. Manure - 3 tons per acre + rock phosphate + CaCO_3 .
7. Green Clover. (turned under)

Pot No.	Treatment	Dry Wt. of mature plant	Total trans.
2	Manure 3T per A	3.46 kilos	2.881 kilos.
3	Manure 6T per A	3.25 "	3.232 "
4	Manure 3T, Rock Phos.	2.85 "	2.729 "
5	Manure 3T, Lime	3.20 "	2.667 "
6	Manure 3 T, Rock Phos., and lime	3.25 "	2.825 "
7	Green Manure	4.49 "	2.130 "

Green manure in this series produced the largest yield and with one exception the total transpiration was the highest. The increase in transpiration was developed in the last few weeks of the growth of the plant.

An application of 6 tons of manure did not increase the dry weight of the plant over an application of 3 tons, although the transpiration was slightly greater.

The use of rock phosphate and lime with manure showed a decrease in both the dry weight and transpiration. The decrease in the former being greater when rock phosphate was applied, and in the latter when lime was applied. When these two were used in combination, with manure the yield in transpiration were both less than when manure was used alone. All of the soils used in these pot experiments are notably deficient in humus, and humus supplying manures in every case except one caused an increase in yield. This one case, e. g., the Dixon soil, is probably due to the lack of the development of proper bacterial flora for the decomposition

LAMAR SOIL

Chart showing total transpiration and dry wt. of mature plant with various treatments

Total transpiration

 Dry wt of mature plant

of the manure. This may have been brought about by the absence of bacteria, or by the development of unfavorable species added in the manure which counteracted their action.

The addition of excessive amounts of manure reduced the yield in several cases. This may have been due to various causes as explained elsewhere.

Lime in addition to the manure increased the yield in most cases. Lime is favorable to the normal decomposition of organic matter, and the favorable results may be attributed to this fact. It has also been claimed by some authorities to increase the availability of phosphates, and it has borne out that theory in most of these series by causing an increase in yield when used in combination with rock phosphate.

The beneficial effect of green manure may in part be attributed to the modification and physical condition brought about by decay of the green material, and in part to the fact that clover is high in nitrogen.

While the results in some of the foregoing series are not altogether consistent, the variations are not great in any case. There is, however, some chance of error in placing the soil in the pot. It is a difficult matter to get the soil in a uniform physical condition in each pot, one may be compacted a little more than another and there may also be some slight difference in the water content, although great care may be taken to secure uniform conditions.

In some of the pot experiments conducted by the Station, some difficulty has been encountered from the development of fungus growths from the manure. As the paraffine pots were sealed it is hard to determine what is going on in the soil. The fact that they are sealed may furnish suitable conditions for the development of certain fungi and bacteria which counteracts the bacteria of normal decomposition and nitrification. The danger from this source can be obviated by using only partially decomposed manure, as the manure used in these tests was fresh.

Humus content of Missouri soils.

In connection with the work of the State Soil Survey a large number of soil samples have been collected, representing many types and phases of each type. The greater part of the samples have been taken in south Missouri where there is an urgent need of supplying the soils with organic matter. The total volatile matter in these soils has been determined from the loss on ignition, and while this includes other volatile components of the soil, such as water or crystallization, and volatile salts, it gives an approximation to the amount of organic matter in the soil. For this reason some of the more important samples have been selected, and their location, etc., and volatile matter given in the subjoined table.

Lab. No.	Depth	Description, location, vegetation, etc.	Volatile matter. Percent
1	0-12 in.	1/4 mile north small store, 5 to 6 miles east of Clinton.	3.560
8	0-12 "	In vicinity of Spruce, high upon Deep Water Creek.	5.110
12	0-11 "	Top of higher flat top ridges of the magnesium limestone belt near Flemington.	2.960
14	0-10 "	Three miles southwest of Humansville.	6.200
16	0- 8 "	2 1/2 miles west of Stockton; top of ridge; rolling pasture land, with sassafras and persimmon saplings.	6.022
20	0-11 "	South of Eldorado, on gentle slope 3/4	6.740
23	0- 7 "	3/4 mile west, and 1/4 mile north of first station on railroad west of Eldorado.	4.360
24.	0-10 "	1/4 mile east of Walker.	3.368
26	0- 8 "	Flat corn field of county farm near Walker.	4.768
28	0- 9 "	6 miles northwest of Walker.	4.972
30	0-10 "	From pasture at eastern edge of plain near Rich Hill.	6.570
32	0- 9 "	6 to 7 miles southeast of Butler.	6.8745
34	0- 8 "	From upland at Pleasant Gap.	3.820
36	0 -8 "	On top of prairie 1/4 mi. south of Weaubleau.	2.668
38	0- 7 "	400 ft. east of the ry. station at Flemington, Polk County.	4.376
40	0-7 "	On flat, 3 mi. south of Dixon.	2.520
42	0-7 "	From sandy pine covered ridge north of Summerville.	4.900
44	0- 7 "	From corn field on stone free land south from Summerville.	2.776
52	0- 7 "	1 mi. north west of Cabool. Top of hill.	2.776

Lab. No.	Depth in.	Description, location, vegetation, etc.	Volatile matter Percent
54	0-7	Flat land northeast of Caboll, in tim. field.	2.990
56	0-7	Sloping bench on west side of Hamilton Creek, Texas County.	1.980
58	0-9	3/4 mi. south of Houston. Limestone bench land; corn fair, clover poor.	4.736
60	0-7	Typically seepy post oak flat. Adjacent corn field, probably on new land looked well.	7.770
62	0-7	1/2 mi. south of Cabool, on top of ridge.	2.926
64	0-7	From corn field ten yrs. in cultivation, about 3/4 mi. south of Hog Creek, on Black Jack slope; corn poor.	2.934
67a	0-7	Near Tyrone.	2.364
68	0-7	At Raymondville.	3.096
70	0-7	Woodland, 1/4 mi. north of Raymondville.	3.442
72	0-7	Lower gentle slope of broad valley; 2 1/2 mi. south of Licking.	3.156
74	0-7	3 or 4 miles northeast of Licking. Abandoned field.	3.025
76	0-7	2 1/2 mi. southwest of Salem.	2.434
80	0-7	1 mi. south of Plato, in clover field.	5.160
82	0-7	1 mi. east of Ellis Prairie, P. O.	2.330
86	0-7	4 mi. north of Roby, Texas Co.; Glasgow's orchard, ten yrs. incultivation; post oak, black jack and black oak.	2.460
94	0-7	Top of ridge 1 mi. north of Waynesville. 250 to 300 ft. above Gasconade River; post oak and black jack, occasional black oak.	3.025
100	0-7	6 mi. west of Crocker, west of Tavern Creek, stony, black jack, post oak and scattering hickory.	2.178

Lab. No.	Depth in.	Description, location, vegetation, et.	Volatile matter Percent
108	0-7	Woodland, 2 mi. S. of Worshom, on Mountain Grove road. Typical black jack flat with occasional pot oak.	1.176
110	0-7	Yard in front of Exp. Sta. Office at Mountain Grove, post oak, black jack, scattering hickory, very stony.	2.790
116	0-7	Post oak flat. 1 mi. E. of Dykes.	4.220
122	0-7	3 1/2 mi. S. of Lenox, On Rolla Road; land eight yrs. in cultivation; black jack on ridge.	3.365
124	0-7	1/2 mi. N. of Vienna, P. O., Crawford Co. on brushy prairie; laurel oak, post oak, white oak and hickory. Rolling. corn good.	1.914
130	0-7	2 1/2 mi. NE of Japan, on Sullivan Road; new land. Black and white oak and hickory ridge.	3.382
136	0-8	1 mi. S. of Richwoods. (upper) on redder part of Richwood plain.	5.788
138	0-7	3 1/2 mi. W. of Washington, at first forks of road on Cambleton road; on slope said to be a little poorer than the average land of the county.	1.472
144	0-8	2 1/2 mi. SW. of New Haven; top of sloping ridge. 3/4 mi. SE. of High Hill, capped with sandstone; clover field.	.664
146	0-8	1 mi. W. of Stony Hill, Gasconade Co.; "buckshot" land.	2.626
150	0-8	5 mi. N. of Owensville, north edge of prairie.	3.080
152	0-8	1 mi. W. of Owensville, Douglas prairie.	2.330
156	0-8	On prairie 1/2 mi. E. of Belle.	5.021
164	0-8	3 mi. SE. of Stott City, sample not taken from highest prairie land.	3.982

Lab. No.	Depth in.	Description, location, vegetation, etc.	Volatile matter. Percent
174	0-7	Black jack flat in Goodman's orchard, in McDonald Co.	2.504
185	0-8	Patterson basin red land.	4.973
187	0-8	1 mi. NE of Piedmont, in valley. Brown color, free of chert. No legumes seen growing.	3.060
195	0-3	Top of ridge south of upper Merrimac valley, 2 mi. S. Stone Hill, P. O., Dent Co.	2.882
207	0-8	5 mi. E. of Salem, N. hillside, clover field, very cherty; black and white oak, scattering post oak.	7.554
209	0-8	Flat woods 2 mi. E. of Purdy, Barry Co.; post oak and black jack.	1.982
221	0-7	Grove Springs, Wright Co.; post oak, black jack and occasional black oak.	1.40
223	0-7	6 mi. E. of Conway; top of rise at head of Brush Creek.	2.712
228	0-7	Top of Libertyville encampment, old field grown to Japan clover.	2.070
230	0-7	4 mi. E. of Perryville; corn field, gently rolling land.	2.494
240	0-7	1 mi. S. Zell Church, St. Genevieve Co.	2.336
241	0-7	5 mi. SW. St. Genevieve; fresh land, high ridge; black oak, black jack, post oak and hickory.	2.546
246	0-7	2 mi. SE. of Libertyville, basin land; fairly good phase.	1.366
251	0-7	Trenton limestone. 2 mi. SE. of Zell, St. Genevieve Co., south of Plank Road. Field where plowed was yellow.	1.447
254	0-7	2 1/2 mi. S. of Bloomsdale, St. Genevieve Co.; patches of fresh land, corn fair.	2.954
256	0-7	Barry Co. Experimental field.	1.738

Lab. No.	Depth in.	Description, location, vegetation, et.	Volatile matter Percent
277	0-10	Audrain Co., sec. 31-52-10; gray silt loam bottom land.	4.686
279	0-8	Audrain Co., sec. 31-52-10, gray silt loam bottom, slightly higher than 277.	7.266
280	0-8	Audrain Co., sec. 27-52-10; flat gray silt loam upland.	3.246
283	0-8	Audrain Co., sec. 21-52-9; gently undulating gray silt loam.	4.996
285	0-8	Audrain Co., sec. 26-52-9; dark loam less sandy phase.	6.124
287	0-8	Audrain Co., sec. 25-52-9; bottom land sand.	1.926
289	0-8	Audrain Co., sec. 12-51-9; black clay loam from weathered shale.	7.312
291	0-8	Audrain Co., sec. 32-51-9; gray silt loam alluvium.	4.592
294	0-10	1 mi. E. of New Hope, Lincoln Co., hickory, oak, elm, and walnut.	1.420
295	0-7	5 mi. NW. of Troy, white oak land.	2.500
298	0-10	1 mi. N. of Rowena, Mercer Co.; top of high level prairie.	3.940
302	0-7	1 mi. N. of Vanoleve, P. O., oak and hickory.	4.122
303	0-7	Sec. 6-36-20; C. H. Franklin's farm, Lone Springs, P. O.; dark silty loam of the prairie.	4.484
304	0-7	Old field NW part of sec. 10-39-13; 5 mi. north of Iberia, post oak and black oak.	4.476
307	0-7	4 mi. SW of Dixon, on the farm of Ed. Piquet, upland ridge and fruit soil.	3.908
323	0-7	From Adrian field. 1 mi. NW of Adrian, Bates Co.	3.360

Lab. No.	Depth in.	Description, location, vegetation, etc.	Volatile matter Percent.
332	0-7	1 mi. NE of Cuba, dark loam to a depth of 8 or 9 inches changing to a reddish clay below.	3.744
333	0-7	1 mi. E. of Kennett, Dunklin Co.; low land sand.	1.478
335	0-7	1 mi. NE of Montreal, P. O.; flat.	2.990
338	0-7	3 mi. S. of Marshfield, Dairmuple land, whitish soil; blue clay subsoil.	2.036
343	0-7	4 mi. W of Competition, black soil, in broad post oak sag on west side of Cobbs Creek.	5.054
347	0-7	Sec. 15-33-16; 1 1/2 mi. S. Lebanon, sadd to be very poor; poor crops.	4.076
350	0-7	3/4 mi. E of Cross Timbers, dark to gray silt.	2.580
352	0-8	Top of Walnut covered limestone ridge. 1 mi. N. of Iberia, black land with few gravel fragments.	6.214
353	0-7	1 1/2 mi. E. of Half Way, P. O., Polk Co. Abandoned land, sandy black oak.	2.340
355	0-7	Sec. 21-25-30; Lawesburg, Dallas Co. white "buckshot" land.	5.744
359	0-7	Sec. 23-34-21; 1/2 mi. N. of Dewey, PO, Polk Co., cherty soil above Hannibal shale.	4.604
362	0-7	Sec. 1-33-18. High prairie only slightly rolling.	3.012
363	0-7	In old field. Sec 6-38-18; Camden Co. 2 mi. SE of Climax Springs, top of Narrow ridge, black and post oak and black jack.	2.730
364	0-7	1/4 mi. west of the County line on the Bolivar road, west of Buffalo, black prairie land.	3.270

Lab. No.	Depth in.	Description, location, vegetation, etc.	Volatile matter Percent
366	0-7	2 mi. SW. of Astoria on typical black oak ridge. Abandoned field.	2.286
368	0-7	1 mi. S. of Oakland, LaCleda Co, gravelly clay, black oak, black jack and hazel, beginning of high country.	2.356
370,	0-7	3 mi. W. of Plato PO, scattering black jack.	2.536
379	0-7	Sec. 24-40-13; Miller Co., new land, about second year in cultivation, silt or clay, black, white and post oak, and hickory.	4.912
381c	0-10	4 1/2 mi. SW. of Garden City,	2.596
382a	0-10	3 mi. W. of Pleasant Hill, alfalfa field of J. B. Millard,	2.042
389	0-10	2 mi. N. of Princeton Hill, silt loam, corn not heavy.	5.820
395	0-7	3 mi. NE of Versailles.	3.760
402	0-8	Barton County, Sec. 5-32-30; rolling phase of gray silt loam.	2.496
403	0-8	Barton Co., sec. 26-31-32;	2.668
405	0-8	Barton Co., sec. 28-33-33, coarse sandy loam with gravelly subsoil.	5.642
408	0-8	Barton Co., sec 30-33-32, flat gray silt loam	3.330
409	0-7	Barton Co., sec. 15-32-30, timber bottom land silt loam.	2.586
410	0-8	Barton Co., sec. 36-31-32;	3.188
413	0-8	Barton Co., 1/4 mi. S. of Boston.	2.942
414	0-7	Butler Co., Nealeyville, N. along rroad adjoining to wn; sand ridge, gray sand, cropped to cotton and corn continuously with no legumes and no manure.	1.460.
420	0-10	On R. C. Young's farm 1 mi. SE. of Campbell, silt loam.	2.080.

Lab. No.	Depth in.	Description, location, vegetation, etc.	Volatile matter Percent
422	0-7	St. Francois bottom, on Mr. Luther Conrad's farm, at corner of Missouri and Arkansas lines within a few feet of the River.	2.720
424	0-7	St. Francois River bottoms, in pasture of Mr. Luther Conrad. 3 1/2 mi. W. of Campbell. Poor land.	2.320
426	0-7	Sandy clay, northeast of Campbell.	4.300
437	0-8	Barton Co., sec. 18-31-30, gray silt loam.	2.840
445	0-7	Barton Co., very coarse sandy loam.	2.700
451 10	0-7	Barton Co., sec. 13-32-33; coarse sandy loam. Rock about 36 in. below the surface.	3.916
452	0-7	Barton Co., sec. 23-32-33; fine sandy loam.	2.880
453	0-7	Barton Co., sec. 7-32-32; fine sandy loam.	4.520
456	0-7	Barton Co., sec. 36-32-33, light gray silt loam.	2.752
458	0-7	Barton Co., sec. 3-32-32;	6.818
459	0-7	Barton Co., sec. 33-32-32; light gray silt loam.	4.540
460	0-7	Barton Co., sec. 9-32-31; coarse sandy loam.	6.400
461	0-7	Barton Co., sec. 20-32-32; dark gray fine sandy loam.	3.920
481	0-10	Low land, Hayti, Mo., alfalfa farming country.	4.800
484	0-10	SE. of Hayti, Pemiscot Co.,	3.060
486	0-10	NE of Hayti, Pemiscot Co.	6.760
502	0-8	Barton Co., sec. 13-31-30; east of Kenoma on smooth land.	4.440
503	0-8	Barton Co., sec. 13-31-30; E. of Kenoma on smooth land.	3.640
508	0-8	Barton Co., sec. 16-31-30; sand knoll, black jack and pot oak land.	.860

Lab. No.	Depth in.	Description, location, vegetation, etc.	Volatile matter Percent
510	0-8	Barton Co., sec. 27-31-39; flat land NE of Golden City.	4.040
513	0-8	Barton Co., sec. 26-31-30; flat lands.	3.780
514	0-8	Bartone Co., under hill on flat land 1/4 mi. SW. of Liberal R. R. Station.	4.640
515	0-7	Barton Co., sec. 15-31-29; stony black oak, black jack and post oak.	2.640
516	0-8	Barton Co., sec. 9-31-30; bech ten feet above sandstone beds in creek.	4.100
520	0-8	Barton Co., sec 13 -33-31; sloping land, red mottled clay subsoil.	4.060
521	0-8	Barton Co., sec. 1-31-33; fine sandy loam.	4.80
522	0-7	Barton Co., sec. 6-31-32; fine sandy loam.	4.940
523	0-10	Barton Co., sec. 35-32-32; flat land.	
524	0-8	Barton Co., sec. 16-32-30; spring river bottom land.	3.580
525	0-8	Barton Co., sec. 14-32-33; flat south of standstone hill.	4.120

From these figures it will be seen that the soils of the State are extremely low in organic matter. There is rarely a case where the total volatile matter exceeds five percent, and a fairly productive soil should contain at least eight percent. These samples were taken, however, in some of the most unproductive sections of the State, and the soils in the northwestern part of the State and the limestone and shale soils south of Kansas City will probably show a much higher percentage of organic matter. A sample taken in the vicinity of Harrisonville showed about eight percent of total volatile matter.

Nearly all the territory from which these samples were taken will grow co^opeas, and a large part of it will grow clover, so that the humus supply can be maintained if these crops are given a place in a systematic crop rotation. Some of the lands are naturally deficient in humus, while others have been cropped continuously so long that it has been remarkably depleted. In either case it demands attention and remunerative crops will result should it be given.

Chapter V. SUMMARY.

In preparing this paper the more important features that have been brought out are as follows:

1. Humus in soils is a very complex substance, its composition depending upon various factors, among them which are its origin, the climatic conditions, such as moisture and temperature, the presence and amount of mineral salts, and the cropping to which the land is subjected.
2. That while humus may not be directly assimilated by agricultural plants, it plays an important part in the fertility of the soil by increasing its water holding power, by improving the tilth, giving better aeration, by the fixation of the soluble bases forming humates which are insoluble, and which are later rendered available by the decomposition of the organic matter, by supplying food and a suitable medium for the bacteria of the soil to work, and binding loose sandy soils together.
3. Continuous cropping without the use of organic manures rapidly decreases the humus and nitrogen content of soils.
4. The humus supply cannot be successfully maintained by a crop rotation in which the soil is in a cultivated crop over one-half the period of the entire rotation, without the addition of some organic manure, such as farm yard manure or green manure.

5. Continued use of mineral fertilizers with no organic manures rapidly decreases the humus supply.

6. Timothy when grown continuously will maintain the humus content of the soil without the addition of manure.

7. Corn is the most destructive crop upon the humus and nitrogen content of soils, the other crops ranking as follows: oats, wheat, timothy.

8. Missouri soils, with very few exception, are low in humus, and all the lands in the State require care in their management in order to maintain the humus content in the ones that have an adequate supply, and build it up where it is deficient.

9. The farmers of Missouri could profitably carry on a rotation which would maintain the humus content of most of the soils in the State.

10. The greater part of the soils in Missouri respond to the application of green manure to a marked degree. Cowpeas, a crop which is particularly valuable as a humus supplying crop, is well adapted to Missouri soils and most of the lands of the State will grow clover.

11. Some lands in the State require an application of lime with manure, in order to secure the best results, while many require an application of phosphorus.

12. The indications are that the application of limestone and rock phosphate in combination produces a netter effect than when either one is used singly.

13. With the wire basket method of determining the needs of the soil the more reliable results are secured by growing the plant to maturity. This is especially true of organic manures as they are not broken down so that they can benefit the plant until the latter stages of its growth. A marked increase in the transpiration during the last half of the period of growth was noted in almost every instance.

Per ct. 0 .5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5

Profile showing
relation of
vol. matter to
humus
in
rotation plats

Humus

Vol. matter

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