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The decomposition of organic matter in soils

Fred G. Merkle
University of Massachusetts Amherst

THE DECOMPOSITION OF ORGANIC MATTER IN SOILS

by

Fred G. Merkle

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INTRODUCTION

Occurrence of Carbon Compounds.

Carbon compounds are universally distributed in all agricultural soils. They are ever being produced and consumed in the natural cycle of the element. The sources of gain in relation to soils are:

1. By bacteria
2. By green plants
3. By rains and snows
4. Absorption of the gas
5. Carbon dioxide from below.

1. Bacteria are usually regarded as liberators rather than fixers of the element carbon, yet species have been isolated which perform the latter function. Kaserer(1) demonstrated the production of organic matter by bacteria growing in inorganic media in an atmosphere containing carbon and hydrogen. The work was confirmed by Nabokish and Lebendeff(2) who showed the disappearence of hydrogen and carbon accompanying their fixation.

2. It is generally, not universally, assumed that green plants take all their carbon from the air. Thus a green crop plowed under will add 300 to 1,000 poūnds of organic matter per acre (dry basis) or approximately .04 per cent. Green plants are, undoubtedly, the greatest source of gain, yet the amount is small in relation to that already existing in the soil. Even poor soils may contain 60,000 pounds per acre.

(1) Kaserer, Cent. Bakt. 2 abt. 15 (1905) p. 573
ibid. abt. 16 (1906) p. 681
(2) Nabokish and Lebendeff, ibid. abt. 17 (1906) p. 350.

3. Rains and snows wash CO_2 from the air, probably combined with NH_3 as ammonium carbonate. Schumacher(3) gives the CO_2 content of rain water as 0.3 to 1.0 volume in 1,000 of rain. Thus, a region having a 36 inch rainfall would annually receive from 400 to 1500 cubic feet of CO_2 or from 50 to 175 pounds of CO_2. Such a figure seems very small, yet it helps to compensate the numerous loses.

4. Soils have an absorptive power for gases, especially carbon dioxide and ammonia. Ferric hydrate, alumina hydrate, humus and clay appear to be the most active soil constituents as regards absorption of CO_2. Reichardt and Blumtritt(4) determined the volume of gas absorbed by equal volumes of various substances and the per cent of CO_2 contained.

ABSORPTION OF CO_2 - REICHARDT AND BLUMTRITT

MATERIAL	Total gas absorbed by 1,000 grams	Per cent CO_2 by volume
Charcoal	164	0
Peat	102	51
Garden soil	14	33
$Fe(OH)_3$	375	70
Fe_2O_3	39	4
$Al(OH)_3$	69	59
Clay moist	29	34
Silt	40	32
$Mg.CO_3$	729	29
$CaSO_4.2H_2O$	17	0

The constituents found abundant in clay, viz. - iron and alumina as hydrates, show a strong absorptive power for CO_2. Peat is relatively high. Von Dobeneck(5) obtained the following results:

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(3) Schumacher, Ernahrung der Pflanze, Berlin (1864) p. 76
(4) Reichardt and Blumtritt, Jour. prakt. chem. 98 (1866) p. 476
(5) Von Dobeneck, Forsch. Agr. Phys. Band 15 (1892) p. 201.

Von Dobeneck		CO_2 absorbed by minerals
Quartz	100 grams	0.023 gr. CO_2
Kaolin	100 grams	0.261 gr. CO_2
Humus	100 grams	1.773 gr. CO_2
$Fe(OH)_3$	100 grams	5.054 gr. CO_2

If we let quartz represent sand and kaolin clay and combine the results of Reichardt and Blumtritt with those of Von Dobeneck it is safe to conclude that the soil's absorptive capacity for CO_2 is largely due to its clay and humus content and to the state of its iron compounds.

To show that soils do actually take on carbon by absorption the results of Lemmerman(6) may be cited. He allowed a kilogram of soil to incubate for a period of eight weeks. The total carbon was determined at the beginning and end of this period and an increase of 0.33 grams was observed in one instance and 0.02 grams in another.

5. Many carbon containing deposits exist within the earth's crust. Just how much carbon may come to the surface from these deposits cannot be determined, but it is probable that methane produced below may gradually rise to the surface and upon reaching better aerated conditions be oxidized to CO_2. The deeper soil layers contain greater quantities of CO_2 than the surface layers. Ebermayer(7) give the following figures at 70 and 15 cm. respectively.

(6) Lemmerman, Aso. Fischer and Fresenius. Landw Jahrb 41 (1911) p. 244

(7) Ebermayer, Forsch auf. die Geb. der Agr. Physik 13 (1890).

Ebermayer	CO_2 content at different depths	
Beech woods	70 cm.	1.19 % CO_2
	15 cm.	.62 " "
Pine woods	70 cm.	9.39 " "
	15 cm.	1.13 " "
Moss	70 cm.	7.98 " "
	15 cm.	1.93 " "
Sod	70 cm.	4.13 " "
	15 cm.	.60 " "
Bare ground	70 cm.	7.02 " "
	15 cm.	1.19 " "

Pfeffer(8) gives the CO_2 content of the soil air at a depth of six meters as 8% or more.

While it is possible that the increased amount of carbon dioxide in the lower layers is due to the downward flow of the gas, it is more probable that it is diffusing up from below, in which case it would be an additive agent.

SOURCES OF LOSS OF CARBON FROM SOILS

Soils may lose carbon: (1) through leaching, (2) through evolution of CO_2, (3) through possible removal by crops.

That soils under certain conditions decrease in organic content is frequently observed. Walker(9) reports a decrease in humus content on non-rotated fields as follows:

Walker	Per cent humus 1895	Per cent humus 1905	Difference
Corn continuous	3.23	2.96	-0.27
Mangels continuous	3.03	2.86	-0.18

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(8) Pfeffer, Physiology of Plants. Ewart, (1899), vol. I p. 171
(9) Walker, Minn. Exp. Station, Tech. Bulletin 128, p. 179.

Rotated fields and fields growing legumes continuously showed a slight gain in the ten-year period. Mooers, Hampton and Hunter(10) show that only when the crop is removed can a decrease in humus content be expected.

1. Loss through leaching. Soils have a strong absorptive power for organic matter; therefore, little or no carbon is lost in that form. To show what a small amount of organic matter is soluble in the presence of soil, analyses by Sutton(11) are here quoted. He analyzed the surface water of cultivated fields and found it to contain but .4 part of organic matter in 100,000, a seeming insignificant amount. If organic matter were subject to loss by leaching we would expect the subsoil of a continuously manured plot to contain more carbon than that of a non-manured plot. Such is not the case. Dyer(12) shows that the subsoil of a plot manured for fifty years contains no more, even less, carbon than that of a plot undunged for forty-one years.

Dyer	Carbon in third 9 inch layer of soil
Dunged 9 years, undunged 41 years	.515 % C
Dunged 50 years	.492 % C

The difference is within the limit of error.

To be capable of leaching organic matter must be soluble and when in solution it is easily precipitated by bases.

Carbon as bi-carbonate of lime is easily lost as is shown by frequent analyses of drainage waters from limed

(10) Mooers, Hampton and Hunter, Tenn. Exp. Station Bulletin 96, part II
(11) Sutton, Volumetric Analysis, 8th Ed. (1900) p. 496
(12) Dyer, Office of Exp. Stations Bulletin 106, p. 39.

fields[13].

2. Some carbon may be lost through evolution of CO_2, but if any the amount must be slight.

3. To say that plants may remove carbon from the soil may seem contrary to our teachings, yet there are numerous evidences that plants may derive a part, at least, of their carbon through their roots.

It has been observed at the Rothamstead Station that poor crops of wheat due to unfavorable climatic conditions have higher percentages of ash elements than good crops. Hence minerals do not seem to be limiting factors. Cameron[14] uses this argument to prove that the use of mineral fertilizers is largely to neutralize toxic substances, but it could be used equally well to show that the synthesis of organic matter, as well as the assimulation of minerals is an important factor in plant growth.

To show the value of organic matter in aqueous extracts of poor soils the Bureau of Soils[15] used a manure extract as follows: One portion of the extract was evaporated and ignited to destroy the organic matter. The other part was used without ignition. The solution to which the unignited manure extract was added gave a far superior growth. Cameron attributes the value of the organic matter in the extract to its probable absorbent action on toxic substances, but it is also probable that the plants absorbed certain organic nutrients from it.

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(13) Hall and Miller, Proc. Roy. Soc. ser B 77 (1905) p. 1
(14) Cameron, The Soil Solution (1911) p. 14
(15) ibid. p. 85.

Gardner[16] determined the effect of many substances, mineral and organic, on transpiration and upon the amount of green matter produced per unit of water transpired. The following figures give the summarized results of many trials:

	Growth due fertilizer	Growth per unit water transpired	Transpiration per unit growth
O check	100	100	100
P	104	103	97.0
K	113	107	93.6
K.P.	118	108	92.6
Lime	127	103	97.0
N	145	116	86.2
N.P.	144	119	84.0
N.P.K.	152	123	81.3
N.K.	154	125	80.0
N.P.K.L.	173	129	77.5
Manure	193	135	74.0
Clover and lime	197	143	69.9

It will be noted that the last two treatments, which are organic, not only gave the greatest growth, but gave the greatest growth per unit of water transpired. This work was done with soil solutions so the effects of the organic matter cannot be due to its action on the physical condition of the soil, nor to its solvent action upon minerals. It is fair to conclude that the presence of carbon in the soil solution decreases the transpiration necessary to produce a unit of dry matter, a strong indication that plants may assimilate carbon through their roots.

Quarrie[17] reports large increases in garden crops through the application of carbon dioxide to the soil through

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(16) Gardner, Bureau of Soils, U.S.D.A. Bulletin 48, p. 54
(17) Quarrie, The Application of CO_2 gas to the Soil; Scientific American, Supplement (1914) p. 399.

pipes. Bornemann[18] reports like results with spinach. Mitscherlich[19], on the other hand, obtained no increase from the application of water saturated with CO_2. The possibility of adding an excess of water or of gas renders the results inconclusive. We know that in ordinary practice CO_2 producing materials are seldom injurious.

DeSassure[20] compared the growth of plants in pure water with water containing one-fourth its volume of carbon dioxide and found that the carbonated water was injurious to growth in the early stages, but not so later in the life of the plant. At the conclusion of the experiment the plants grown in the carbonated water weighed 46.4 grams, while those growing in pure water weighed 45.5 grams.

Hellreigel and Wilfarth[21], Franke[22], Berthelot[23], and Schoessing and Laurent[24] all report the utilization of organic nitrogen by green plants. Schreiner[25] and his associates have isolated createnine, an organic nitrogen compound, from soils and proved its beneficial action upon plant growth.

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(18) Bornemann, D.L.G. 28 (1913) No. 31, p. 443
(19) Mitscherlich, E.A., Landw Jahrb, Bd 39 (1910) p. 157-166
(20) DeSassure, Theod. Recherches Chemiques sur la Végétation. Paris 1804, p. 27 and 28
(21) Hellreigel and Wilfarth, Ann. Agron. Tome XV
(22) Franke, Ann. de la Soc. Agron. Tome II
(23) Berthelot, Ann. de Chim et de Phys. Tome XIII, p. 5
(24) Schloessing and Laurent, Ann. de l'institute Pasteur Tome VI
(25) Schreiner, Shorey, Sullivan and Skinner, U.S.D.A. Bureau of Soils Bulletin 83.

Lefèvre[26] grew plants in an artificial soil made from sand and moss, supplied with amids and sterilized so that further oxidation of these compounds would be avoided. The entire plant was enclosed in an atmosphere freed from carbon dioxide. Under such conditions it is evident that any growth must result from the assimilation of the amids. Lefèvre obtained normal growth and concludes that: 1. In a soil supplied with amids one may develop green plants without carbon dioxide. 2. [27]The growth thus produced is a real synthesis not a (pousée aqueuse). 3. [28]Without light synthesis from amids is impossible.

So much for nitrogenous organic substances. Molliard[29], using glucose, and Laurent[30] and Knudson[31], using other carbohydrates have shown that plants assimilate sugars and that these sugars are used to synthesize dry matter.

Ravin[32] compared the effects of organic acids with their acid and neutral salts and concluded that such organic

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(26) Lefèvre, Jules, Sur le developpement des plantes vertes a la lumiere en l'absence complete de gas carbonique dans un sol artificial des amides. Comptes. Rendus. 141 (1905) p. 211-213, also p. 664-665
(27) Ibid., p. 834-835
(28) Ibid., p. 1035-1036
(29) Molliard, M., Culture pure des plantes vertes dans une atmosphere confinée en présence des matiéres organiques. Comptes.Rendus.141 (1905) p. 389-391
(30) Laurent, M.J., Recherches sur la Nutrition Carbonée des Plantes Vertes a L'aide de Matiéres Organiques. Revue General de Botanique, Tome 16 (1904) p. 14-48
" " " " " " " p. 96-117
(31) Knudson, Lewis, Influence of certain Carbohydrates on Green Plants. Cornell Memoir 9 (1916)
(32) Ravin, Nutrition Carbonée des Phanerogames a L'aide de quelques acids organiques et de leur sels potassiques. Comptes. Rendus. 154 (1912) p. 1100-1103.

acids as malic, tartaric, citric, succinic and oxalic may be assimilated by plants and further that these organic acids are more nutritive than their corresponding salts or acid salts.

So far we have considered the assimilation of carbon from materials of known composition; namely, CO_2, amids, carbohydrates and organic acids. Molliard[33], to put the matter on a more practical basis, experimented with humus extracted from soil. The work was carried on under sterile conditions, but it was impossible to prevent, entirely, the evolution of CO_2; therefore, definite conclusions cannot be drawn.

The most conclusive proof that green plants can take up carbon compounds through their roots is their growth with the foliage enclosed in an atmosphere entirely devoid of carbon dioxide. Pollacii[34] grew plants in a culture bottle within a large receptacle, each being provided with tubes so that the water or air in each may be renewed and controlled independently of the other. The plants were sealed into the stopper with wax. By adding CO_2 to the nutrient solution and excluding it from the aerial portions of the plant he has successfully grown plants and even revived the chlorophyl in etiolated leaves.

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(33) Molliard, M., L'humus est il un source direct de Carbon pour plantes vertes superiense? Comptes. Rendus. 154 (1912) p. 291-294

(34) Pollacii, G., Nuove Recherche Sull'assimilazione Del Carbonio. Bullitinino Della Societa Botanica Italiana (1911 and 1912) p. 208-211.

From the evidence in the foregoing pages it may be concluded that green plants can, and probably do, take carbon through their roots. Just what form or what proportion of the total carbon in the plant this may be cannot be stated, but the fact itself is enough to make us turn our attention to the soil organic matter.

DECOMPOSITION OF ORGANIC MATTER

Hopkins[35] states that: "It is the decay of organic matter and not the mere presence of it that gives life to the soil. Partially decayed peat produces no such effect upon the productive power of the soil as follows the use of farm manures or clover residues." Löhnis[36] declares that the organic matter is the life of the soil and upon its decay depends the fertility of the soil.

Realizing the importance of organic matter and its decomposition with reference to soil fertility many investigations, demonstrating the rate of decay and factors influencing it, have been made.

Van Suchteln[37] has used the rate of decay, measured by carbon-dioxide production, as a measure of bacterial activity. This method recognizes CO_2 as the ultimate and most representative end product of decay. He showed the influence of moisture and of frost, the effect of soluble sugars and of salts on bacterial activity. His results showing the action of fertilizers on the rate of decay are closely related to our subject and will be reported. He mixed the materials in six Kg. of soil and determined the amount of carbon dioxide produced in twelve hours.

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(35) Hopkins, Soil Fertility and Permanent Agriculture (1910) p. 195

(36) Löhnis, Boden Bakterien and Boden Fruchtbarkeit.

(37) van Suchteln, Uber die Messung der Lebensthatigkeit der aerobischen Bakterien im Boden durch die Kohlensauer produktion. Cent. Bakt. etc. Abt. 2, Bd 28 (1910) p. 45.

van Suchteln		Action of Fertilizer Materials
6 kg. soil	No addition	145 mg. of CO_2
" " "	+ 90 gr. $MgSO_4H_2O$	408 " " "
" " "	+ 6 gr. CaO	62 " " "
" " "	+ 30 gr. $(NH_4)_2SO_4$	864 " " "
" " "	+ 6 gr. Superphosphate	306 " " "

The increases from applied materials are quite large with the exception of lime, which has evidently absorbed the gas produced. One function of fertilizers may be to hasten the decay of organic matter.

Lemmerman(38) and associates worked with the influence of lime compounds on decay. They compared the oxide and carbonate. They found that CO_2-production could not be taken as a measure of bacterial action with lime, because the oxide absorbed and the carbonate gave up CO_2. To offset the difficulty they carried on balance experiments in which the total carbon was determined before and after the incubation period, which lasted eight weeks. Their experiments show that (1) lime hastens decay, (2) kainit and a mixture of kainit and superphosphate does not increase decay, (3) dry organic matter decays as rapidly as the same material fresh.

Potter and Snyder(39) report some work along this line. In their experiments the soil was placed in pots under bell

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(38) Lemmerman, Aso. Fischer and Fresenius, Untersuchung uber die Zerzetzung der Kohlenstoff verbindugen verscheidener organischer Substanzen im Boden speżiell under dem Einfluss der Kalk. Landw Jahrb. 41 (1911) p. 216-257

(39) Potter and Snyder, Carbon and Nitrogen Changes in the Soil variously treated with Ammonium Sulphate and Sodium Nitrate. Soil Science Vol. I, No. 1 (1916) p. 76-94.

jars and the CO_2 evolved was measured by drawing air over, not through, the soil. Their observations will be mentioned later.

Fred and Hart[40] showed that sulphate of ammonia, sulphate of potash and phosphates increased the carbon dioxide production, the first named to a marked degree.

Russell[41] measures oxidation by determining the oxygen absorbed rather than the CO_2 produced. Either method should give about the same results, for many analyses show that a high oxygen content of soil air is accompanied by a low CO_2 content and vice versa. In other words the sum of the oxygen and carbon dioxide is nearly constant.

Russell's method is to place the soil in a flask, connected on one side to a KOH flask and on the other side to a mercury tube. The KOH absorbs any CO_2 evolved and the rise of mercury in the other arm indicates the oxygen absorbed.

He determined the oxidation of many soils by this method and concluded that (1) in different soils of the same type the rate of oxidation varies in the same way as the fertility and may be used as a measure of it. This, if true, is important, for we have no other laboratory method of determining the relative fertility of soils.

EXPERIMENTAL

The work of previous investigators indicates oxidation to be a measure of fertility in soils; hence, the rate of

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(40) Fred and Hart, Comparative Effect of Phosphates and Sulphates on Soil Bacteria. Wis. Research Bul. 35

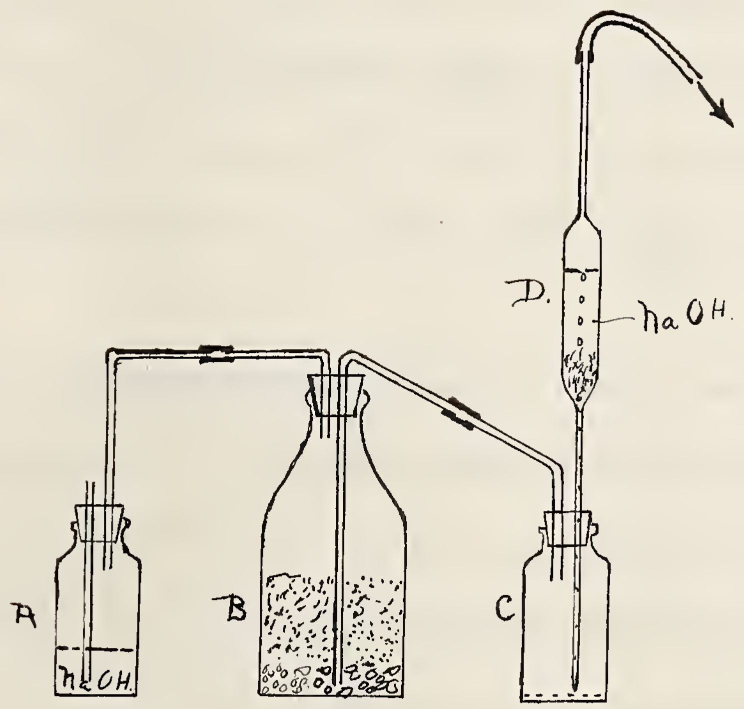
(41) Russell, Journal Agricultural Science. Vol. I (1905) p. 261-279.

oxidation of organic additions should be a measure of their effectiveness. For the purpose of comparing organic materials ordinarily added to the soil the following series of experiments were planned.

For determining the rate of oxidation quart milk bottles were used. They were fitted with two-holed rubber stoppers, one hole carrying a short glass tube while the other carried a tube reaching to the bottom of the bottle. Both tubes were fitted with short rubber connections stopped with glass plugs. Two hundred grams of washed gravel were placed in the bottom of the bottle to facilitate aeration and afford a space for the excess CO_2. The organic substance used in the test was thoroughly mixed with 300 grams of moist soil (25% water) and placed on top of the gravel. The soil was moderately compacted by tamping.

The soil used was a fine, sandy loam of alluvial formation which had been under cultivation for many years. It was stored in covered ash barrels and not allowed to dry out, so the original bacterial flora was sufficient for the work. To make sure of this one bottle was inoculated with 10 cc. of a manure suspension. This bottle gave the same amount of CO_2 as the uninoculated one after the first week of incubation, showing that there was no deficiency of organisms.

The rate of oxidation was determined by measuring the amount of CO_2 produced each week as follows. The rubber connections were closed with pinch cocks, the glass plugs removed and the bottles connected with the absorption bottles,



D.
NaOH.
A
NaOH.
B
C

as shown in the diagram. First is an absorption bottle (A) containing NaOH to free the incoming air of CO_2. Next is the incubation bottle (B) with its outlet tube reaching the bottom to make sure of complete removal of the CO_2 produced. The absorption apparatus (C) was devised to take the place of a Reisset[42] absorption tower. The tower (D) is an ordinary 100 cc. pipet filled with broken glass or beads to increase the absorption surface. The pipet is connected with a Chapman filter pump. It was found that a rapid stream of air could be drawn through this tower without danger of incomplete absorption, and also that four minutes of strong aspiration was sufficient to remove all CO_2 from the generating flask.

Each bottle was aspirated once a week, using 500 cc. of $\frac{N}{2}$ NaOH as the absorbent. The CO_2 was determined by the double titration method[43]. A 10 cc. aliquot of the carbonated soda is titrated with phenolpthalein against HCl, first using normal acid until near the neutral point. Neutralization is completed with $\frac{N}{10}$ acid. This marks the conversion of carbonate to bi-carbonate, neutral to phenolpthalein.

$$Na_2CO_3 + HCl + \text{phenolpthalein} \longrightarrow NaHCO_3 + NaCl.$$

The amount of acid needed to make this change need not be known, nor is it necessary to know the normality of the alkali used.

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(42) Reisset, Compte. Rendu. Vol. 38, p. 1001 and Vol. 90, p. 1144

(43) Brown and Escomb, Proc. Roy. Soc. 76 (1905) p. 29.

Methyl orange is now added and $\frac{N}{10}$ HCl run in drop by drop till the neutral point is reached. The exact amount is recorded and is equivalent to the CO_2 contained.

$NaHCO_3 + HCl + mo. \longrightarrow NaCl + H_2O + CO_2.$

One cubic centimeter of $\frac{N}{10}$ HCl equals 4.4 milligrams of CO_2.

Cochineal gives about the same results as methyl orange, but the latter was used throughout this work.

EXPERIMENT I

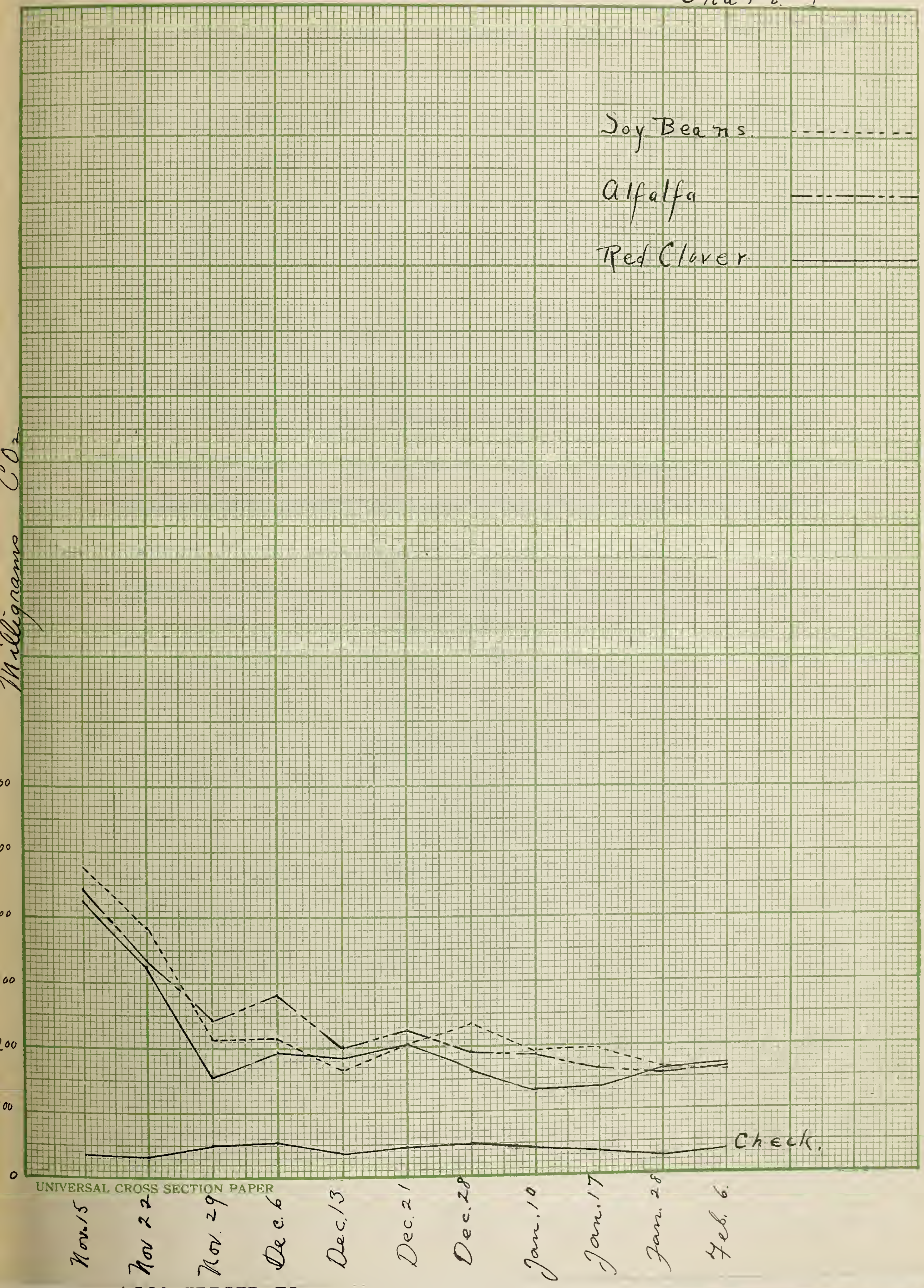
LEGUME FODDERS

The plants were cut off at the surface of the ground when in full bloom or as near that stage as possible. They were dried, slowly at first and later in the oven. When dry they were ground and reground until all the material would pass through a 2 mm. sieve. Fifteen grams were mixed with 300 grams of moist loam, placed in the inoculation bottles on top of a layer of gravel and slightly compacted. The bottles were stoppered and the outlet tubes closed with glass plugs. They were allowed to incubate in the dark at room temperature, the CO_2 produced being measured weekly (usually) in the manner just described. An untreated soil served as a check for all the following experiments.

TABLE I MILLIGRAMS CO_2 PRODUCED

Date	Loam 300 gr. Untreated	Loam 300 gr. + soy bean fodder 15 gr.	Loam 300 gr. + alfalfa fodder 15 gr.	Loam 300 gr. + red clover fodder 15 gr.
Nov. 15	35.2	475.2	444.4	426.8
Nov. 22	33.0	385.0	336.6	325.6
Nov. 29	50.0	211.0	242.0	154.4
Dec. 6	52.0	213.4	281.6	195.8
Dec. 13	37.4	167.4	200.2	182.6
Dec. 21	48.4	206.8	228.8	206.8
Dec. 28	50.6	237.6	193.6	162.8
Jan. 10	41.8	191.4	189.2	132.0
Jan. 17	37.4	195.8	167.2	143.0
Jan. 28	28.6	167.2	158.4	162.0
Feb. 6	35.2	160.6	165.0	169.4
TOTALS	449.6	2611.4	2607.0	2220.8

Chart I


Soy Beans
Alfalfa
Red Clover
Check
Milligrams CO_2
0
UNIVERSAL CROSS SECTION PAPER
Nov. 15
Nov 22
Nov. 29
Dec. 6
Dec. 13
Dec. 21
Dec. 28
Jan. 10
Jan. 17
Jan. 28
Feb. 6.

The above figures are plotted in Chart I. They show that a rapid production of CO_2 takes place the first two weeks after a legume fodder starts to decay, and that after the second week they settle down to a steady rate of decomposition. Apparently red clover decays a little slower than the other fodders, but there is no great difference between them.

There are possibilities of errors in the aspiration of the gas, but the irregularities in the curves are due to these. Temperature changes affect all alike, hence the general tendency is for all to rise and fall at the same period, though not always in the same degree. The uniformity of the check indicates the accuracy of the method. Duplicates were run in the early part of the experiment but the close agreement seemed to justify dropping them to save work.

HUMUS PRODUCTION

Equally important as the rate of oxidation is the humus produced. A substance may oxidize very rapidly, as for example sugars, and still not increase the humus content noticeably. Such substances would be of questionable value as regards the physical improvement of the soil. Unpublished work[44] shows that sugars break up very rapidly in the soil and are nearly completely oxidized within a week or two. Lactose, maltose, saccharose, dextrose and fructose run about the same. Sugar beets (Chart II) in the early stages of decay show the effect of their sugar, but later gave about the same results as the rape and swedes.

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(44) Writer's.

The materials used in the CO_2 production experiments, having been allowed to incubate from November 8th to February 19th, were removed, dried and their humus content determined by the official method. The results are recorded together with the total CO_2 production for comparison.

TABLE II HUMUS PRODUCTION

	Humus, per cent	Total CO_2 - Cg.
Soil No treatment	2.96 %	44 Cg.
" + Alfalfa	3.43 "	260 "
" + Red clover	3.29 "	220 "
" + Soy beans	3.285"	261 "

The figures indicate that there is little choice between the legumes in decay and humification.

EXPERIMENT II

ROOT CROPS AND RAPE

These substances were used to compare readily decomposable carbohydrates, as found in plants, with more inert materials. For this purpose sugar beet roots, swede or rutabaga roots and rape tops were used. All of these contain some form of stored food, sugar or starch. The plants were taken from the field, air dried, then oven dried, and ground fine enough to pass a 2 mm. sieve. Fifteen grams of each were mixed with 200 grams of moist soil and placed in incubation bottles as previously described.

Determinations of CO_2 produced were made weekly.

TABLE III MILLIGRAMS CO_2 PRODUCED

Date	Loam 300 gr. Untreated	Loam 300 gr. + sugar beets 15 gr.	Loam 300 gr. + swedes 15 gr.	Loam 300 gr. + rape 15 gr.
Nov. 15	35.2	550.0	464.2	400.4
Nov. 22	33.0	708.4	484.0	396.0
Nov. 29	50.0	213.4	261.8	231.0
Dec. 6	52.0	235.3	226.6	244.2
Dec. 13	37.4	171.6	162.8	165.0
Dec. 21	48.4	132.0	189.2	206.8
Dec. 28	50.6	160.0	165.0	182.6
Jan. 14	41.8	125.4	147.4	158.4
Jan. 17	37.4	103.4	132.0	110.0
Jan. 28	28.6	118.8	114.4	149.6
Feb. 6	35.2	106.8	140.8	156.2
TOTALS	449.6	2625.6	2488.2	2400.2

Sugar beets, Chart II, as might be expected, show rapid decay at the start but the sugar is all oxidized in two weeks, after which time the organic matter in them is no more decomposable than that of other materials. Rutabagas contain but little sugar and decay no faster than legume fodders. Rape is slowest at first but as time goes on it exceeds the others.

Comparing the legumes with roots we find that the former are more readily oxidized as time goes on, that is, after the sugar in the roots is broken down.

HUMUS PRODUCTION

The results of the humus determination are as follows:

TABLE IV

	Humus, per cent	Total CO_2 - Cg.
Soil No treatment	2.96 %	44 Cg.
" + Swedes	3.56 "	248 "
" + Sugar beets	3.28 "	262 "
" + Rape	3.24 "	240 "

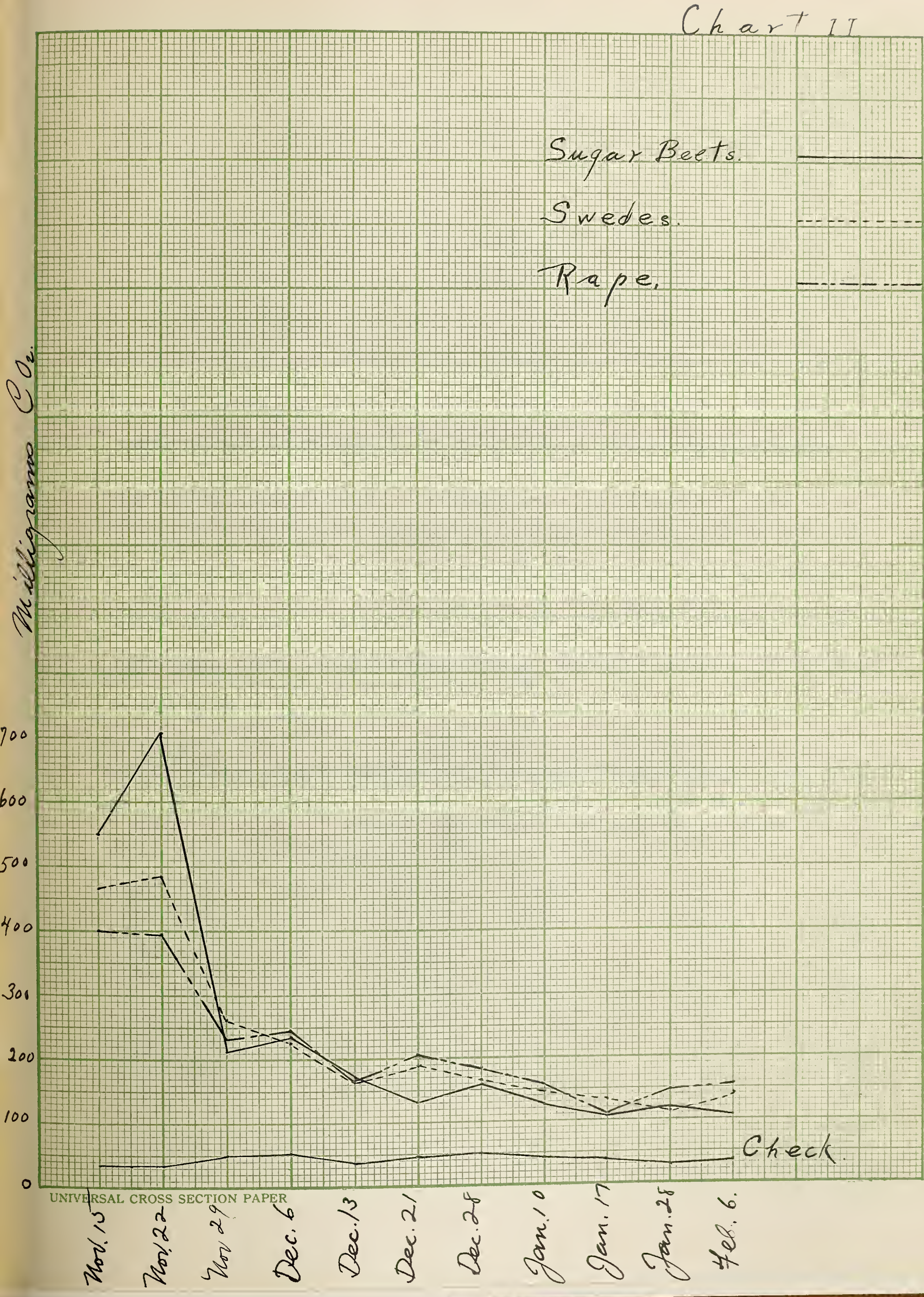
Chart II
Sugar Beets.
Swedes.
Rape.
Milligrams Co.
700
600
500
400
300
200
100
0
Check.
UNIVERSAL CROSS SECTION PAPER
Nov. 15
Nov. 22
Nov. 29
Dec. 6
Dec. 13
Dec. 21
Dec. 28
Jan. 10
Jan. 17
Jan. 25
Feb. 6.

The difference as shown by the humus figures seems the more representative, since the higher CO_2 production for sugar beets is due to the sugar. Rape falls in third place in both instances.

EXPERIMENT III

LITTERS

The materials listed below find their way into the soil through natural agencies or as litters and were selected with the expectation of obtaining large differences. It was thought that pine needles might even lower the bacterial activity, at least for a time.

Pine needles, oak leaves and maple leaves were picked while still green, air dried and later oven dried. White pine shavings, as used for litter, were oven dried. Each substance was ground and sieved. Fifteen grams were used in each case.

TABLE V MILLIGRAMS CO_2 PRODUCED

Date	Loam 300 gr. Untreated	Loam 300 gr.+ Shavings 15 gr.	Loam 300 gr.+ Maple leaves 15 gr.	Loam 300 gr.+ Oak leaves 15 gr.	Loam 300 gr.+ Pine needles 15 gr.
Nov. 15	35.2	257.4	275.6	338.8	343.2
Nov. 22	33.0	257.4	250.8	303.6	259.6
Nov. 29	50.0	118.8	224.4	182.6	224.4
Dec. 6	52.0	156.2	211.2	178.2	167.2
Dec. 13	37.4	103.4	206.8	187.0	193.1
Dec. 21	48.4	88.0	184.8	180.4	184.8
Dec. 28	50.4	105.6	167.2	162.8	178.2
Jan. 10	41.8	101.2	171.6	147.4	151.8
Jan. 17	37.4	77.0	149.6	158.4	136.4
Jan. 28	28.6	132.0	143.0	149.6	134.2
Feb. 6	35.2	74.8	160.6	116.6	110.0
TOTALS	449.6	1471.8	2145.0	2105.4	2083.4

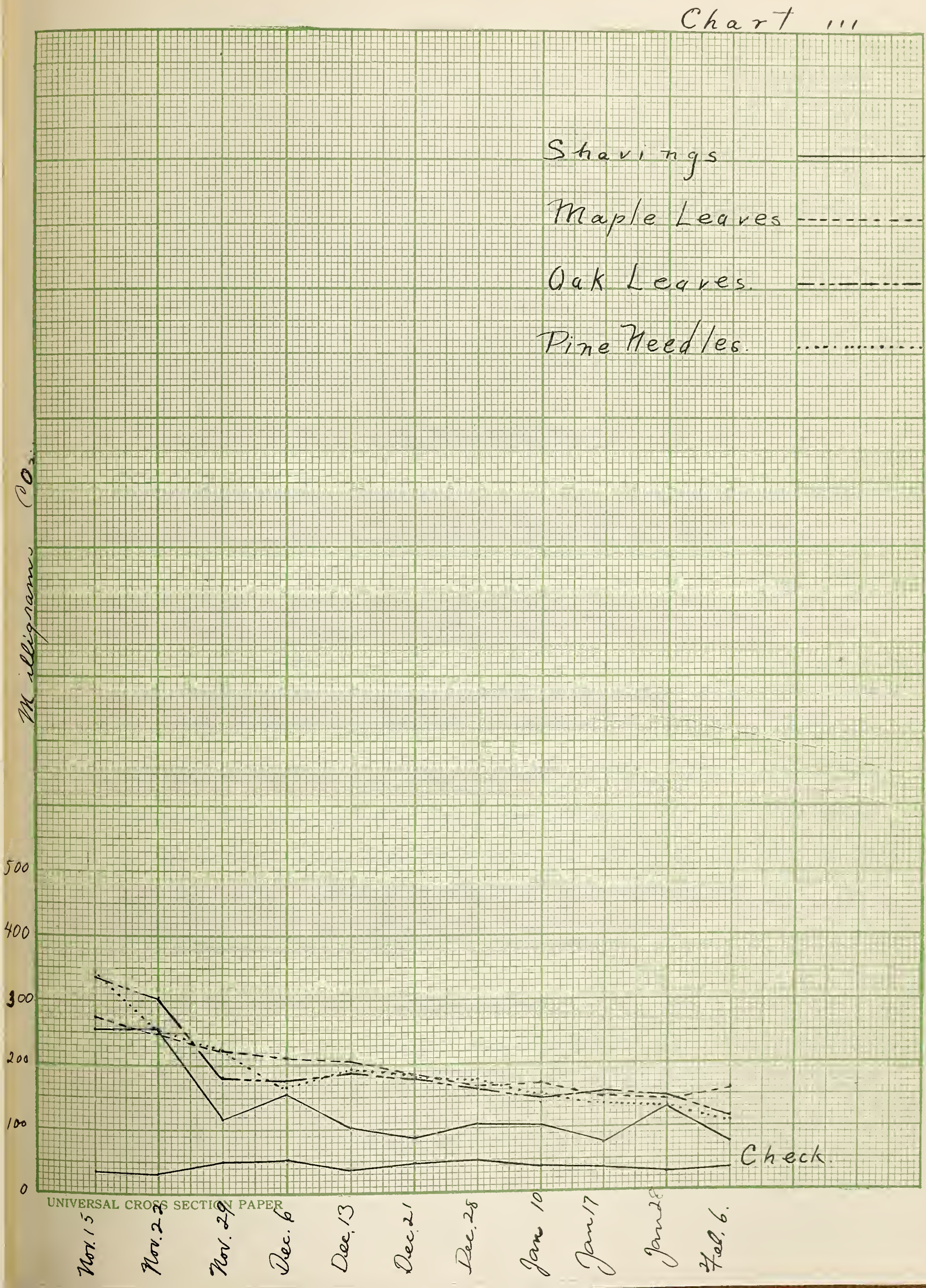

Chart III
Shavings
Maple Leaves
Oak Leaves.
Pine Needles.
Milligrams CO2
500
400
300
200
100
0
Check.
Nov. 15
Nov. 22
Nov. 29
Dec. 6
Dec. 13
Dec. 21
Dec. 28
Jan 10
Jan 17
Feb. 6.
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See Chart III.

White pine shavings stand out as a striking example of an inert substance, being lowest and slowest in CO_2 production. Maple leaves give a more uniform decline than anything else.

The litters in general, as might be expected, are not as rapidly decomposed as either legumes or root crops and suggest the importance of nitrogen as an aid to oxidation, as those materials which are low in nitrogen are slow to oxidize. This latter statement applies to the later stages of decomposition.

HUMUS PRODUCTION

TABLE VI

		Humus, per cent	Total CO_2 - Cg.	
Soil	No treatment	2.96 %	44	Cg.
"	+ Maple leaves	3.345 "	214	"
"	+ Oak leaves	3.18 "	210	"
"	+ Pine needles	3.07 "	208	"
"	+ Shavings	2.91 "	147	"

The rate of oxidation, as measured by humus production and CO_2 production, follow the same order; namely, (1) maple leaves, (2) oak leaves, (3) pine needles, (4) pine shavings. It should be noted that the shavings after having been in the soil for three or four months did not increase the per cent of humus, in fact, lowered it slightly.

EXPERIMENT IV

CEREALS AND BUCKWHAT

Barley, oats and buckwheat were used because good samples of them were available. Barley and buckwheat are quite

frequently plowed under as green manure crops, which is not true of oats. Plants that were half matured were dried, ground and mixed with the moist loam. The rate of oxidation was as follows:

TABLE VII MILLIGRAMS CO_2 PRODUCED

Date	Loam 300 gr. Untreated	Loam 300 gr. + Oats 15 gr.	Loam 300 gr. + Buckwheat 15 gr.	Loam 300 gr. + Barley 15 gr.
Nov. 15	35.2	349.8	442.2	428.8
Nov. 22	33.0	338.8	283.8	380.6
Nov. 29	50.0	242.0	176.0	341.0
Dec. 6	52.0	239.8	182.6	281.6
Dec. 13	37.4	176.0	184.8	191.4
Dec. 21	48.4	253.0	138.6	195.8
Dec. 28	50.6	184.8	125.4	176.0
Jan. 10	41.8	189.2	162.8	138.6
Jan. 17	37.4	176.0	160.6	134.2
Jan. 28	28.6	184.8	158.4	118.8
Feb. 6	35.2	147.4	136.4	123.0
TOTALS	449.6	2481.6	2151.6	2529.2

See Chart IV

Little or no consistent variation occurs. Buckwheat appears to be the most inert.

HUMUS PRODUCTION

TABLE VIII

		Humus, per cent	Total CO_2 - Cg.
Soil	No treatment	2.96 %	44 Cg.
"	+ Oat fodder	3.185 "	248 "
"	+ Barley fodder	3.10 "	252 "
"	+ Buckwheat fodder	2.99 "	208 "

Oats and barley are very nearly the same, the variation being within the limits of error. Buckwheat seems to be a very inert substance, increasing the per cent of humus almost

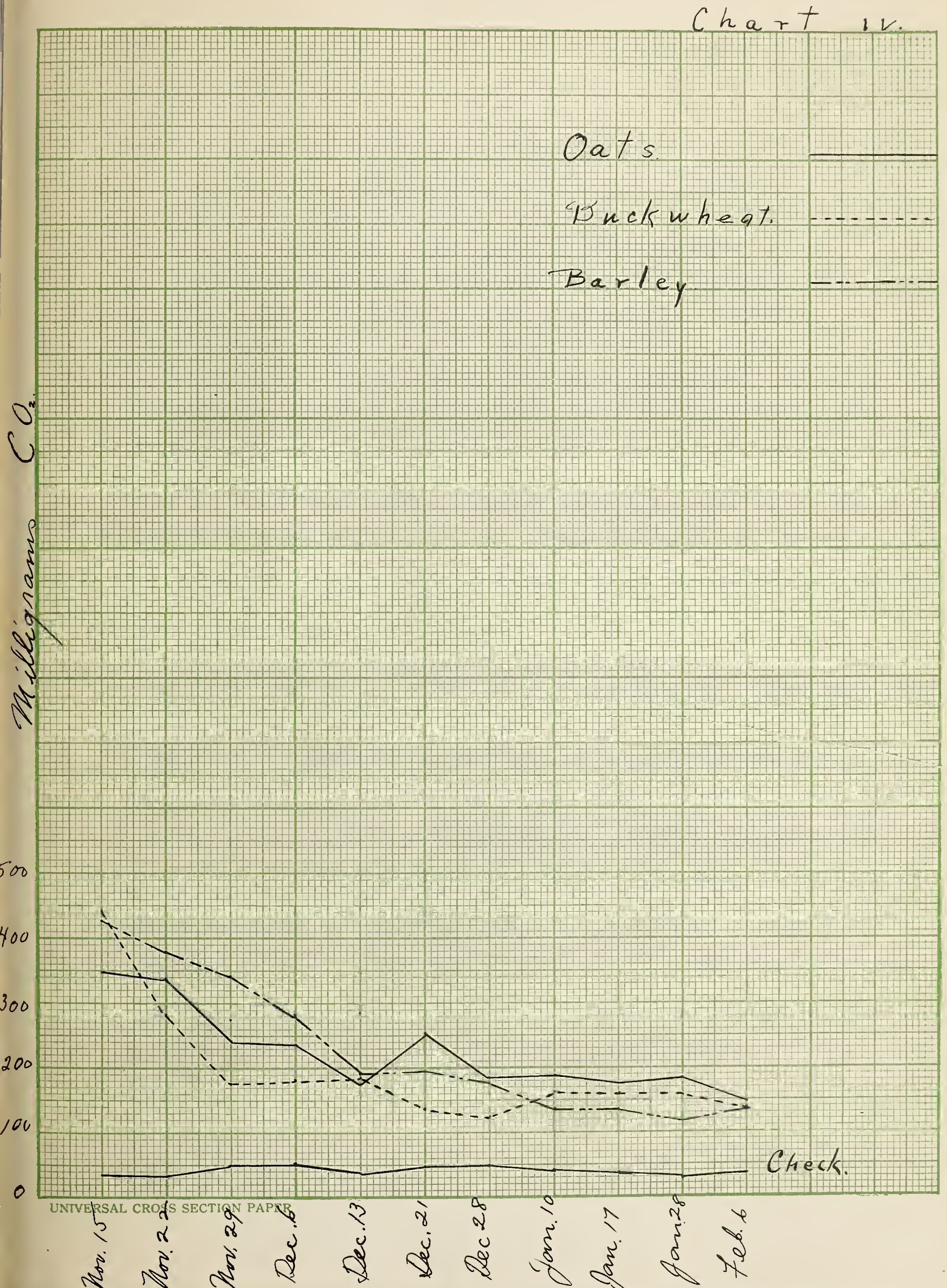

Chart IV.
Oats.
Buckwheat.
Barley
Milligrams CO2.
500
400
300
200
100
0
Check.
UNIVERSAL CROSS SECTION PAPER
Nov. 15
Nov. 22
Nov. 29
Dec. 6
Dec. 13
Dec. 21
Dec 28
Jan. 10
Jan. 17
Jan. 28
Feb. 6

nil, while the total CO_2 given off in three months is considerably lower than the other materials.

GENERAL OBSERVATIONS

Before the experiment was started it was expected that a wide variation in the rate of decomposition would be shown. Wollney[44] states that: "Legume straws containing a high nitrogen content are easily decomposed, grain straws are more resistant, while leaves and needles are still more so." The results show this to be true, but the difference is not as marked as might be expected. That white pine shavings should increase the CO_2 production as much as they did is peculiar, so it seems that the increased aeration afforded by the loose material has had some effect in causing a greater recovery of CO_2.

It should be remembered that all substances were dried before using, which may account for the uniformity of the results, although Lemmerman[45] found no difference between green and dry lucern. It would be nearly impossible to obtain, at the same time, all of the materials at the proper stage of growth and normal moisture content. To place everything on the same basis it seemed advisable to dry each in the same degree.

For the sake of comparison the humus production of all the materials is given on Chart V. It is believed that these results fairly represent the availability of the substances used.

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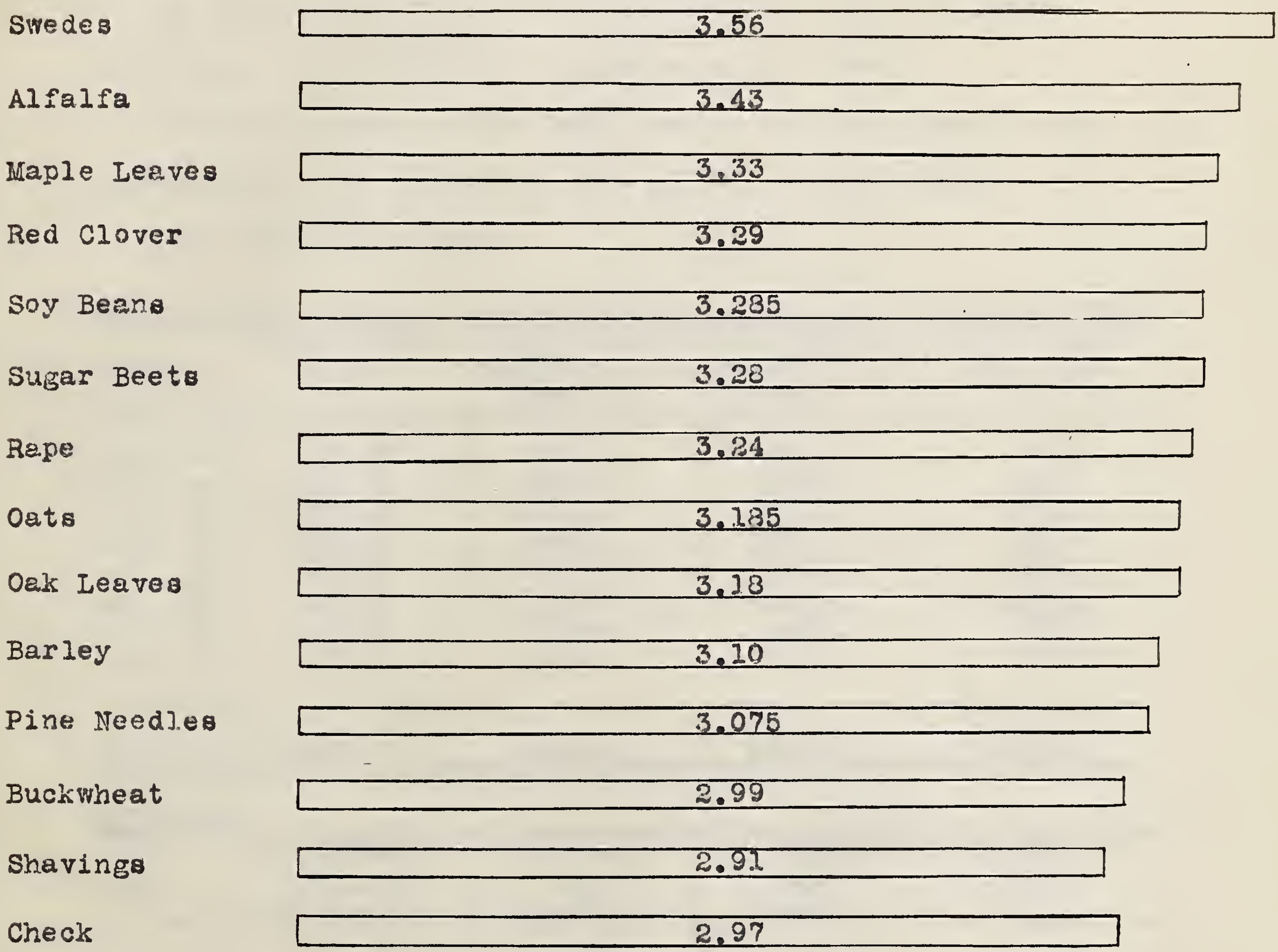
(44) Wollney, Die Zerzetzung der Organischen Stoffe, p. 405
(45) Lemmerman, loc. cit.

Chart V



HUMUS PRODUCTION

ACTION OF FERTILIZERS ON DECOMPOSITION

A second series of experiments was run along the same period as those just cited in an effort to determine whether or not fertilizer materials increased the rate of decomposition. The same form of apparatus was used.

Fifteen grams of soy bean fodder and one gram of the fertilizer to be tried out were added to each flask.

The results follow:

Date	Soy beans alone	Soy beans + Sulphate of Ammonia	Soy beans + Nitrate of Soda	Soy beans + Amm. Phos.
Nov. 15	475.2	437.8	431.2	289.4
Nov. 22	385.0	365.2	545.6	374.0
Nov. 29	211.2	220.0	279.4	136.4
Dec. 6	213.4	228.8	297.0	198.0
Dec. 13	169.4	158.4	211.2	180.4
Dec. 28	237.6	187.0	235.4	224.4
Jan. 17	195.8	138.6	158.4	173.8
Jan. 28	117.2	145.2	143.0	154.0
TOTALS	2054.8	1881.0	2301.2	1830.4

Continued

Date	Soy beans + Calcium Cyanamid	Soy beans + Acid Phosphate	Soy beans + Raw Bone	Soy beans + Basic Slag
Nov. 15	244.2	411.2	296.0	413.6
Nov. 22	330.0	374.0	341.0	389.4
Nov. 29	195.8	195.8	228.8	193.6
Dec. 6	206.8	209.0	209.0	283.8
Dec. 13	321.0	180.4	169.4	259.0
Dec. 28	182.6	195.8	220.0	242.1
Jan. 17	283.8	171.6	167.2	187.0
Jan. 28	162.8	132.0	156.2	173.8
TOTALS	1927.0	1870.0	1887.4	2141.4

Continued

	Soy beans Sulphate of Potash	Soy beans Kainit	Soy beans Muriate of Potash	
Nov. 15	446.6	352.0	407.0	
Nov. 22	409.2	255.2	191.4	
Nov. 29	209.2	224.4	204.6	
Dec. 5	184.0	202.4	204.6	
Dec. 13	191.4	158.4	136.4	
Dec. 23	217.8	228.8	171.6	
Jan. 17	147.4	167.2	134.2	
Jan. 28	154.0	112.2	112.2	
TOTALS	1952.8	1700.6	1562.0	

The results show that but two of the fertilizer materials tried out increase the rate of decay; they are nitrate of soda and basic slag. The others show but little effect with the exception of kainit and muriate of potash, which decrease the rate quite markedly. The results with kainit agree with the carbon balance experiments of Lemmerman, previously mentioned.

Calcium cyanamid contains carbon so it is not fair to draw any conclusions regarding its effect on organic decay as measured by CO_2 production. However, it appears to be toxic to soil bacteria as is shown by the markedly lowered production the first two weeks. This toxic action seems to last but one week, agreeing with the recommendations of Brooks, Schneidewand and others that the material be applied a week or two before planting time.

More experimental work of this kind has been done with sulphate of ammonia than any other fertilizer and contradictory results have been obtained. Van Suchteln, using a light application of sulphate of ammonia and measuring the CO_2 for

a very short period (12 hours), obtained much more gas from the treated soil. Fred and Hart(46) made determinations at two day periods and, while an increase over the check is shown, it is not nearly as great as the above. Potter and Snyder(47) found a slight decrease in CO_2 production from the use of sulphate of ammonia as did the writer. The results of the last two experiments are not entirely contradictory to the former, for the time factor enters. It seems that the immediate effect of the salt is to increase or stimulate bacterial action, but it is not lasting. The results obtained here, as well as those of Potter and Snyder, represent a length of time equivalent to a growing season and for that reason should be of more practical value.

EFFECT ON HUMUS CONTENT

The residues from the oxidation experiments were dried and their humus content determined.

The results were as follows:

EFFECT OF FERTILIZERS ON HUMUS CONTENT

Treatment		Per cent humus
Soy beans 15 gr.	Alone	3.285 %
" " " " +	Kainit, 1 gr.	3.225 "
" " " " +	Raw ground bone, 1 gr.	3.195 "
" " " " +	Muriate of Potash, 1 gr.	3.180 "
" " " " +	Sulphate of Ammonia, 1 gr.	3.175 "
" " " " +	Acid Phosphate, 1 gr.	3.155 "
" " " " +	Calcium Cyanamid, 1 gr.	3.130 "
" " " " +	Sulphate of Potash, 1 gr.	3.035 "
" " " " +	Ammo Phos, 1 gr.	3.000 "
" " " " +	Rock Phosphate, 1 gr.	2.990 "
" " " " +	Basic Slag, 1 gr.	2.970 "
" " " " +	Nitrate of Soda, 1 gr.	2.865 "

(46) Fred and Hart, loc. cit.
(47) Potter and Snyder, loc. cit.

Those materials which markedly depressed the production of CO_2, viz., kainit and muriate of potash caused the least loss in humus. This is shown by the relatively high humus content in the jars treated with those substances. On the other hand the materials which increased the production of CO_2, viz., slag and nitrate of soda, have markedly lowered the humus content. Considering this one may infer that fertilizers act upon the soil humus and not upon the crude organic matter. One would expect the continued use of materials like nitrate of soda to cause a rapid depletion of the soil's humus content.

SUMMARY AND CONCLUSION

1. The legumes which are high in nitrogen show a more rapid rate of decay than straws and litters which are low in nitrogen. Nitrogen, then, seems to influence decomposition.
2. On farms where animal manures are not available the choice of green manures and cover crops is important. The results indicate that legumes would be most desirable on such farms.
3. Cyanamid appears to be toxic to soil bacteria, or at least arrests the decay of organic matter for two weeks after application.
4. Commercial fertilizers apparently act upon soil humus, decomposing it quite rapidly. They apparently do not act upon crude organic matter in the same way.