The Decomposition of Organic Matter in Relation to
Soil Fertility in Arid and Semi-arid Regions

by

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DEDICATION

Respectfully dedicated to Drs. T. F. Buehrer and
R. A. Greene, whose assistance and sympathy were
an inspiration in the preparation of this thesis.

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TABLE OF CONTENTS

INTRODUCTION	Page 1
SCOPE OF INVESTIGATION	11
EXPERIMENTAL PROCEDURE AND RESULTS	14
I. Influence of organic matter on the liquid phase of the soil	14
a. Effects on aqueous (1:5) extracts	14
b. Percolation studies	23
II. Decomposition studies	27
a. CO ₂ evolution as an index to rates of decompo- sition	27
b. Decomposition of "pure" organic compounds in the presence of soil	32
c. Effect of moisture on the decomposition of organic matter	34
d. Effect of temperature on the decomposition of organic matter	39
e. Fractionations of different organic materials	43
f. Fractionations of organic matter in the pres- ence of soils	50
III. Neubauer studies	57
DISCUSSION	63
SUMMARY AND CONCLUSIONS	91
BIBLIOGRAPHY	94

LIST OF TABLES

	Page
TABLE I. EFFECT OF ORGANIC MATTER ON AQUEOUS (1:5) EXTRACTS. GILA FINE SANDY LOAM. CHECK, NO TREATMENT.	16
TABLE II. GILA FINE SANDY LOAM ONE PERCENT MANURE.	16
TABLE III. GILA FINE SANDY LOAM ONE PERCENT ALFALFA.	16
TABLE IV. GILA FINE SANDY LOAM ONE PERCENT HEGARI.	17
TABLE V. GILA CLAY LOAM. CHECK, NO TREATMENT.	17
TABLE VI. GILA CLAY LOAM ONE PERCENT MANURE.	17
TABLE VII. GILA CLAY LOAM ONE PERCENT ALFALFA.	18
TABLE VIII. GILA CLAY LOAM ONE PERCENT HEGARI.	18
TABLE IX. PIMA CLAY. CHECK, NO TREATMENT.	18
TABLE X. PIMA CLAY ONE PERCENT MANURE.	19
TABLE XI. PIMA CLAY ONE PERCENT ALFALFA.	19
TABLE XII. PIMA CLAY ONE PERCENT HEGARI.	19
TABLE XIII. PERCOLATION STUDIES. EFFECT OF ORGANIC MATTER ON SOLUBLE SALTS, pH, CALCIUM, ETC. (GILA FINE SANDY LOAM)	25
TABLE XIV. EFFECT OF ORGANIC MATTER ON CO ₂ PRODUCTION.	29
TABLE XV. DECOMPOSITION OF VARIOUS "PURE" ORGANIC COMPOUNDS IN THE PRESENCE OF SOIL.	33
TABLE XVI. INFLUENCE OF MOISTURE (AS PERCENT OF THE WATER-HOLDING CAPACITY) ON THE DECOMPOSITION OF ORGANIC MATTER.	36
TABLE XVII. INFLUENCE OF TEMPERATURE ON THE DECOMPOSITION OF ORGANIC MATTER.	41
TABLE XVIII. CHEMICAL COMPOSITION OF MANURE AT DIFFERENT STAGES OF DECOMPOSITION.	45

LIST OF TABLES (CONTINUED)

	Page
TABLE XIX. CHEMICAL COMPOSITION OF ALFALFA AT DIFFERENT STAGES OF DECOMPOSITION.	46
TABLE XX. CHEMICAL COMPOSITION OF HEGARI SORGHUM AT DIFFERENT STAGES OF DECOMPOSITION.	47
TABLE XXI. CHEMICAL COMPOSITION OF ALFALFA AT DIFFERENT STAGES OF DECOMPOSITION IN THE PRESENCE OF GILA FINE SANDY LOAM.	55
TABLE XXII. CHEMICAL COMPOSITION OF ALFALFA AT DIFFERENT STAGES OF DECOMPOSITION IN THE PRESENCE OF TUBAC CLAY LOAM.	55
TABLE XXIII. EFFECT OF ORGANIC MATTER ON AVAILABILITY OF PHOSPHATES AND POTASSIUM.	59
TABLE XXIV. COMPARISON OF RESULTS ON THE DECOMPOSITION OF ALFALFA IN ARID AND HUMID REGIONS (PERCENT BASIS).	

LIST OF PLATES

- Plate 1. EFFECT OF ORGANIC MATTER ON SOLUBLE SALTS (1:5 EXTRACTS). GILA FINE SANDY LOAM.
- Plate 2. EFFECT OF ORGANIC MATTER ON pH AND PHOSPHATES (1:5 EXTRACTS). GILA FINE SANDY LOAM.
- Plate 3. EFFECT OF ORGANIC MATTER ON NITRATES (1:5 EXTRACTS). GILA FINE SANDY LOAM.
- Plate 4. PERCOLATION STUDIES ON GILA FINE SANDY LOAM. EFFECT OF ORGANIC MATTER ON pH AND CALCIUM.
- Plate 5. PERCOLATION STUDIES ON GILA FINE SANDY LOAM. EFFECT OF ORGANIC MATTER ON BICARBONATES.
- Plate 6. PERCOLATION STUDIES ON GILA FINE SANDY LOAM. EFFECT OF ORGANIC MATTER ON SOLUBLE SALTS.
- Plate 7. THE EFFECT OF ORGANIC MATTER ON CO₂ PRODUCTION. (GILA FINE SANDY LOAM)
- Plate 8. MILLIGRAMS CO₂ PRODUCED FROM 50 GRAMS GILA FINE SANDY LOAM AND ONE PERCENT OF GLUCOSE, STARCH, CELLULOSE AND LIGNIN (30° C.).
- Plate 9. DECOMPOSITION OF ORGANIC MATTER AS A FUNCTION OF MOISTURE.
- Plate 10. EFFECT OF MOISTURE ON RATES OF DECOMPOSITION AS COMPUTED FROM SLOPE OF CURVES IN PLATE 9.
- Plate 11. DECOMPOSITION OF ORGANIC MATTER AS A FUNCTION OF TEMPERATURE.
- Plate 12. EFFECT OF TEMPERATURE ON RATES OF DECOMPOSITION AS COMPUTED FROM SLOPE OF CURVES IN PLATE 11.
- Plate 13. DECOMPOSITION STUDIES ON MANURE..
- Plate 14. DECOMPOSITION STUDIES ON ALFALFA.
- Plate 15. DECOMPOSITION STUDIES ON HEGARI SORGHUM.
- Plate 16. DECOMPOSITION OF ALFALFA IN THE PRESENCE OF GILA FINE SANDY LOAM.

LIST OF PLATES (CONTINUED)

- Plate 17. DECOMPOSITION OF ALFALFA IN THE PRESENCE OF TUBAC CLAY LOAM.
- Plate 18. ACTUAL RATES OF DECOMPOSITION OF DIFFERENT ORGANIC FRACTIONS.
- Plate 19. MILLIGRAMS OF P_2O_5 ABSORBED BY RYE SEEDLINGS. GILA FINE SANDY LOAM.
- Plate 20. MILLIGRAMS OF K ABSORBED BY RYE SEEDLINGS. GILA FINE SANDY LOAM.
- Plate 21. COMPARATIVE RATES OF DECOMPOSITION OF ORGANIC MATTER IN ARID AND HUMID REGIONS.
- Plate 22. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF ALFALFA IN ARID AND HUMID REGIONS.

INTRODUCTION

All agricultural soils contain organic matter in varying amounts, depending chiefly on climatic factors and cultural practises. Its physico-chemical nature and biological transformation have been the subject of extensive study, especially since the importance of microorganisms in relation to soil fertility and plant growth became realized. It is remarkable, however, that most investigational work has been confined primarily to the humid regions, and the major object of this dissertation is a critical study of organic matter as related to some of the more important phases of soil fertility in arid and semi-arid regions. Generally speaking, the agricultural soils of these areas are characterized by their great deficiency in both organic matter and nitrogen, but the role played by the organic fraction in the maintenance of soil fertility in these regions is but poorly understood. Furthermore, the general trend in agricultural practises seems to be towards greater diversity and complexity, which necessitates an appreciation of the various factors which underlie soil fertility.

Obviously, such a study is a complicated one, for not only is one confronted with the complex nature and transformations of organic matter itself, but also with its various direct and indirect effects on soil, plant and microbe.

The problem has been further complicated by the advent of artificial fertilizers, which marks an altogether new era in agricultural development. Finally, it is realized that short-range experiments are often insignificant when compared with the ages required for the soil to have reached its present state of dynamic equilibrium. Nevertheless, there is great need for a better understanding in connection with the functions of organic matter in the drier regions, and this investigation is undertaken with the hope of throwing light on some of the more important aspects of the problem.

A critical study of the voluminous literature finds it lacking lamentably with respect to the arid regions. No attempt will be made to give a complete review, inasmuch as this has been admirably done by Waksman (83). This investigator has made an exhaustive study of the origin, nature and transformations of soil organic matter with the result that at present we have a fairly good knowledge of the subject. Analytical methods have also been developed whereby it is possible to make quantitative determinations on the organic fraction of soils - i.e., accurate determinations of both total amount and chemical nature are possible.

Dismissing the origin, nature and microbial transformation, one naturally searches the literature for exact data bearing on the problem of soil fertility. Organic matter

has been hailed as "the cure for everything", especially as far as physical soil conditions are concerned. Thus it is believed to "bind" the sandy soils, render the clays more friable, at the same time improving moisture and aeration relationships. Alway and Neller (2), however, conclude that the physical benefits of organic matter have been totally over-estimated, especially in the drier regions, whereas Thorne (80, 81) reaches more or less similar conclusions. These investigators believe that the physical improvements attributed to organic matter are more likely due to superior root-development induced by the nitrogen and mineral elements, especially in the case of manure. Other investigators, including Hibbard (27), Johnson, Thompson and Sahr (35), Sprague and Marrero (70) and Muller (54) reach almost similar conclusions as those cited above. Keen (38) has made an exhaustive study of physical soil conditions, but is unable to reach any definite conclusions as to the influence of organic matter.

The writer (56), investigating the problem with respect to green-manuring in the summer rainfall areas of South Africa, produced convincing evidence that it is almost impossible to increase permanently the supply of either organic matter or nitrogen in the semi-arid and sub-humid regions. Green manures disappear rapidly and completely from these soils and the only feasible practice seems to be a livestock

industry where hay crops and legumes are fed to animals, the manure returned to the land, supplementing with suitable phosphatic fertilizers. These conclusions were confirmed by Theron and van Wyk (77) who showed that green-manuring is a failure in the arid and semi-arid regions of South Africa, being unable to increase the soil's store of either organic matter or nitrogen. The single cropping system, using phosphatic fertilizers is just as good a practice as rotations with legumes in maintaining soil fertility. "Green manuring is only effective on soils which require the assistance of this agency in the replacement of electrolytes in the liquid phase, notably when the latter is subjected to constant depletion through leaching" (loc. cit.).

A critical survey of the green manure problem in the U. S. A. leads Pieters (60) to conclude that this practice is not feasible in the Great Plains and the drier regions. Greaves (23,24) at Utah has also shown that crop rotations including legumes are not able to maintain permanent fertility. Legumes draw themselves heavily on soil nitrogen and can not increase this element when the whole crop is removed for hay or otherwise. The author was unable to obtain any critical data from the arid and semi-arid regions of India or Australia, but what little evidence is available (1, 58) seems to indicate that green manuring, together with an attempt to maintain or increase the soil's store of organic

matter is completely overshadowed by factors like lack of moisture and application of phosphatic fertilizers.

Both Stewart (73) and Russel (65, 66) agree that organic matter does not have the same importance in arid as in humid sections. Active azofication may play a very important role in arid regions, and the best practice appears to be the returning of all crop residues to the soil, supplementing with suitable phosphatic and nitrogenous fertilizers. These authors conclude that it is only natural for the organic matter to drop when virgin soils are brought into cultivation. Furthermore, attempts to restore this level of organic matter in arable farming are uneconomical, apart from the fact that crops may "burn" following organic matter applications. "It is extravagant to build back run-down soils any further than the point at which crops utilize most profitably all the nitrogen supplied in manures." (loc. cit. 65) →

Investigations by Blair (5, 6), Jenny (33), Hunt (30), Jones and Yates (26), Sievers and Holtz (68), Fippin (21) and others are all in substantial agreement with these findings, although Jordan (37), Swanson (75), Roberts and Ewan (64), and Kennedy (39) report favorably on the influence of organic matter both in general fertility and yields. Burgess (13) also stresses the beneficial effects of manure in the reclamation of alkali soils, whereas Breazeale and

Burgess (10) and McGeorge, Buehrer and Breazeale (49) have shown that CO_2 and pH are the key to phosphate availability in calcareous soils. The complete absence or great deficiency of CO_2 in black alkali soils is the greatest factor concerned in the low fertility of many of these soils and from this standpoint, addition of organic matter will have beneficial effects. →

By far the greater amount of work on soil organic matter deals with its chemical nature and microbiological transformations to form "humus". Waksman (83) has given complete and extensive reviews of the voluminous literature, so that only the more outstanding facts need to be mentioned. It is now generally agreed that carbon dioxide is the most important end-product of microbiological processes, chiefly due to the dissolution property as carbonic acid. →

Thus Brown and Gwinn (12) found that both organic matter and sulfur increase the solubility of rock phosphate under laboratory conditions, whereas Hopkins, Whiting and Albert (29) believe that CO_2 produced by respiration and microbial metabolism markedly assist the plant in obtaining phosphorus, calcium and nitrogen. Jensen (34) also reports increased solubility of calcium, magnesium, iron and phosphorus in citrus soils at Riverside, due to inorganic salts contained in green manures together with the solvent action of soluble organic compounds. He further suggests that the beneficial

effects of manure on chlorosis may be due to increases in the solubility of iron compounds. MacBeth (46) reaches more or less similar conclusions.

Stephenson (72), and Bauer (3) on the other hand report negligible solubility effects of CO_2 and conclude that the benefits derived from organic fertilizers are due primarily to the liberation of the plant food elements by microorganisms together with increases in colloidal matter. Parker (57), in a study on the influences of CO_2 produced by plant roots and mineral absorption, concludes that, while plants differ as to CO_2 production, mineral absorption evidently shows no correlation with the amount of CO_2 produced by roots or that present in the soil air. Many investigators, including Waksman and Starkey (89), Potter and Snyder (62), Bell (4), Smith and Brown (69), Starkey (71) and others have also measured CO_2 (and to a lesser extent nitrates) as representing rates of decomposition of organic matter. Generally speaking, the fertile soils show the higher rates, although often no direct relationship seems to exist.

Lundegårdh (43, 44), Gerlach and Seidel (22), Stoklasa (74) and many others have studied the CO_2 factor from another angle. Up to concentrations of about one percent, CO_2 is found to be a limiting factor in photosynthesis under laboratory conditions and, inasmuch as the soil is regarded as the most important source of CO_2 to plants, decomposing

organic matter would make for increased yields. Densch (19), however, in a critical study of the problem, concludes that CO_2 assimilation by plants is governed more by factors like light, heat and moisture than by the quantity of CO_2 in the atmosphere or soil. Mach (45) and Lemmermann (41) reach almost similar conclusions. Riedel (63) and Borneman (7) obtained marked increases in yields by introducing CO_2 from blast furnaces by means of pipes in hot beds and open fields, but both Lemmermann (41) and Gerlach and Seidel (22) could not obtain increased yields when various organic fertilizers were used as sources of CO_2 . Noyes and Weghorst (55) have also shown that CO_2 may have harmful residual effects on plant roots when introduced artificially into the soil. →

McGeorge (47) has shown that organic matter is capable of chemical equivalent base exchange reactions, that this property rests largely with the lignin-fraction, being a linear function of the carbon content, but in no way related to the C:N ratio. These results were later confirmed by Mitchell (51) and others.

One expects and also finds a great deal of conflicting evidence with respect to the effect of organic matter on the yields of succeeding crops. Theron and van Wyk (77) and the writer (56) have shown that green manuring is a failure in the sub-humid and semi-arid regions of South Africa, whereas Thorne (80, 81) finds that the highest

yields on the Broadbalk Field Plots are obtained by chemicals alone. Daji (17), de Turk (20) and others conclude that artificial fertilizers are more efficient and economical than organic manures, whose main value lies in their nitrogen content and mineral elements. Pittman (61), Harris (25) and many others on the other hand report favorably on both green manures and animal manures as far as yields are concerned.

Bottomley (8) was probably the first to call attention to the possible existence of growth-promoting substances or "auximones". "It is now generally established that plants, in their turn, require growth-promoting substances or "auximones" which, in the case of lower plants, are apparently manufactured by themselves but which, in the case of green plants, must be supplied from without. Since these accessory substances are essentially organic in nature, their only possible source in the case of ordinary green plants is to be found in the organic matter of the soil in which they are growing." (loc. cit.)

Mockeridge (52) and, more recently, Breazeale (9), in a critical study of this problem conclude that certain plants, on decomposing, develop compounds which stimulate the growth of other plants. Thus the stimulating property of manure lies in the black, water-soluble organic matter and not in the plant foods, phosphorus, nitrogen and potas-

sium added. Furthermore, seedlings show that, for normal development, some require organic compounds, not usually considered as plant foods. Finally, the beneficial effects of manure and crop rotations are believed to be due to the organic matter added which, on decomposition, sets free certain compounds that are essential to plant growth. Clark and Roller (15, 16), on the other hand, conclude that organic matter is not essential for *Lemna major*. "Auximones" are hence not essential for the growth of green plants and can not be classed with vitamins, which are essential for animal growth.

SCOPE OF INVESTIGATION

The last few decades have witnessed remarkable developments and advances in our knowledge concerning the various phases of soil fertility and plant growth. Of these, few, if any, have received the attention of soil organic matter or humus. The problem has been studied from many different aspects - physically, chemically, biologically - a voluminous literature, excellently reviewed and compiled by Waksman (83), has accumulated, and there is no doubt that at the present time we have a fairly good knowledge as to its origin, chemical nature and microbiological transformations in soils. Nevertheless, we feel that there is a lack of co-ordination of the various factors, possibly insufficient cooperation and sympathy between soil scientist and plant physiologist, perhaps some confusion due to various economic factors that have tended to entangle and complicate the agricultural situation. In order to evaluate the function of any one factor like humus, it is essential to study all angles of the problem, both theoretically and practically. Inasmuch as very few critical data are available with respect to arid and semi-arid regions, it is the endeavor of this investigation to study the problem from its various applied and practical aspects, rather than from one or possibly two angles.

Organic matter affects the soil physically, chemically and biologically, but the author is convinced that, as far as the arid and semi-arid regions are concerned, the physical aspects are of minor importance. The soils of these regions are characterized by their relative stability and constructive genesis, and, barring the Solonchets, show excellent aeration and other physical relationships. Furthermore, convincing evidence has been produced by several investigators that the addition of organic matter has little, if any, effect on moisture relations. No attempts will therefore be made to study any physical aspects of the problem, although the author feels inclined to think that fairly heavy applications of organic matter might actually have harmful effects in alkaline soils due to dispersion produced by lyophilic organic colloids.

The chemical and biological factors, however, were regarded as the most important and the following studies were undertaken:

- I. The influence of different types of organic matter on the soil solution as obtained by
 - a. 1:5 water extracts,
 - b. percolation methods.

Such studies are of fundamental importance, since the plant is primarily concerned with the concentration of different nutrient ions in the liquid phase.

II. Decomposition studies, which are essential for an understanding of the various chemical and biological transformations brought about by microorganisms.

The following factors were investigated:

- a. Rates of decomposition of different organic materials as obtained by CO_2 evolution.
- b. Rapidity of decomposition of various "pure" substances such as glucose, starch, cellulose and lignin when incorporated with soils, as measured by CO_2 evolution.
- c. Effect of moisture on CO_2 production and the relation of moisture to decomposition of organic matter.
- d. Influence of temperature on rates of decomposition as measured by CO_2 evolution.
- e. Fractionations of various organic materials at different stages of decomposition in order to follow the fate of the different complexes during microbial decomposition.
- f. Attempts to fractionate organic matter in the presence of different types of soils as an endeavor to trace the changes produced by microorganisms under field conditions.

III. Neubauer investigations, in which the effect of different types of organic matter on the availability of phosphorus and potassium in soils were studied.

EXPERIMENTAL PROCEDURE AND RESULTS

I. Influence of organic matter on the liquid phase of the soil

a. Effects on aqueous (1:5) extracts

The growing plant is pre-eminently concerned with the soil solution and, inasmuch as decomposing organic matter is believed to increase the solubility of various plant nutrients, the first set of experiments is an attempt to follow the influence of different organic materials on the liquid phase as indicated by 1:5 water extracts.

Three calcareous soils were selected from series in the Tucson area, the mechanical analyses of which showed them to be Gila Fine Sandy Loam, Gila Clay Loam and Pima Clay. These three types represent the usual range of agricultural soils in these areas. As organic materials were selected fresh cow manure, alfalfa (about half-bloom stage) and mature stalks of hegari sorghum.

Duplicate 100 gram samples of each soil were weighed into glass tumblers with the following treatments: (1) check, no treatment, (2) one percent air-dry, powdered manure (20 mesh), (3) one percent air-dry alfalfa and (4) one percent hegari. Moisture was brought to the optimum and the tumblers incubated at room temperature (approximately 30° C. during summer), the moisture being kept at the opti-

mum. After definite intervals of time, treated and control soils were analysed as follows: the contents of the tumblers were transferred to wide-mouth bottles with 500 cc. of CO_2 -free distilled water, placed in an end-over-end shaking machine and shaken for one hour. The bottles were then allowed to stand for a few minutes so that the heavier particles could settle. Total soluble salts were determined on this supernatant liquor by means of a portable conductivity bridge, while pH measurements were made by means of the hydrogen electrode.

Following this, the suspensions were saturated with CO_2 for 15 minutes, filtered, and the filtrates analysed for phosphates, using the colorimetric molybdenum-blue method (26), while nitrates were determined by the phenol-disulfonic acid method. pH is expressed on 1:5 extracts whereas soluble salts (T.S.S.), phosphates (CO_2 -soluble PO_4) and nitrates (NO_3) are given in parts per million on the air-dry soil. The results are indicated in Tables I-XII and a representative set of data is graphically represented in Plates 1, 2 and 3.

TABLE I. EFFECT OF ORGANIC MATTER ON AQUEOUS (1:5) EXTRACTS. GILA FINE SANDY LOAM - CHECK, NO TREATMENT.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.60	375.0	13.50	50.6
1	8.69	757.5	13.50	49.3
2	8.67	605.0	14.00	54.6
3	8.73	580.0	15.60	83.7
5	8.71	455.0	13.20	138.5
8	8.56	680.0	11.50	116.5
12	8.61	617.5	15.60	180.0
20	8.75	605.0	20.00	240.0

TABLE II. GILA FINE SANDY LOAM + ONE PERCENT MANURE.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.68	622.5	53.0	72.0
1	8.59	637.5	61.5	14.0
2	8.68	560.0	59.7	10.1
3	8.71	570.0	59.0	24.0
5	8.71	570.2	57.5	81.8
8	8.52	740.0	54.0	120.0
12	8.59	795.5	72.5	257.0
20	8.60	920.1	90.0	360.1

TABLE III. GILA FINE SANDY LOAM + ONE PERCENT ALFALFA.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.23	1120.0	9.25	36.0
1	8.49	950.0	10.44	75.0
2	8.38	1220.0	11.88	313.0
3	8.38	1222.5	13.60	400.1
5	8.43	1330.0	12.80	514.3
8	8.32	1505.5	12.50	600.0
12	8.42	1635.0	15.0	719.4
20	8.44	1655.0	24.8	900.0

TABLE IV. GILA FINE SANDY LOAM + ONE PERCENT HEGARI.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.44	915.0	15.00	48.6
1	8.64	592.5	17.32	8.8
2	8.71	575.0	17.50	7.0
3	8.80	602.5	16.00	0.0
5	8.78	550.0	15.51	0.0
8	8.72	620.0	14.00	0.0
12	8.78	590.0	18.50	0.0
20	8.70	580.0	52.50	1.5

TABLE V. GILA CLAY LOAM. CHECK, NO TREATMENT

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	9.12	731.0	7.75	109.0
1	9.17	730.0	10.75	102.8
2	9.10	716.5	8.25	106.05
3	9.17	760.0	8.00	106.0
5	9.18	610.1	7.25	138.0
8	9.07	775.0	6.75	128.6
12	9.20	670.1	10.40	179.2
20	9.10	775.2	12.50	200.0

TABLE VI. GILA CLAY LOAM + ONE PERCENT MANURE.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	9.04	992.5	32.00	217.8
1	8.89	917.5	52.75	50.0
2	8.91	860.0	41.73	40.0
3	9.09	812.5	42.50	31.0
5	9.10	812.5	42.00	91.1
8	8.95	930.0	42.00	112.5
12	8.98	955.0	58.00	112.0
20	9.01	1025.1	25.00	134.0

TABLE VII. GILA CLAY LOAM + ONE PERCENT ALFALFA.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.56	1040.0	8.37	59.00
1	8.67	1427.5	5.00	64.80
2	8.67	1285.0	8.00	112.50
3	8.74	1552.5	8.00	400.00
5	8.73	1595.0	8.75	849.40
8	8.63	1850.2	9.25	720.00
12	8.70	1905.1	11.60	900.00
20	8.67	1910.0	17.50	902.10

TABLE VIII. GILA CLAY LOAM + ONE PERCENT HEGARI.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.73	1277.5	7.75	83.1
1	8.93	950.0	7.40	94.7
2	9.07	875.0	9.87	10.0
3	9.11	870.2	8.75	10.0
5	9.05	815.4	7.25	0.0
8	9.09	870.0	7.50	0.0
12	9.18	775.0	9.50	0.0
20	9.15	763.0	13.60	0.0

TABLE IX. PIMA CLAY. CHECK, NO TREATMENT.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.49	530.0	10.57	65.2
1	8.52	522.0	11.60	124.5
2	8.52	565.2	12.25	105.9
3	8.53	580.0	12.60	120.0
5	8.44	582.5	10.50	150.0
8	8.42	660.0	11.40	156.5
12	8.58	705.0	11.50	200.0
20	8.51	710.0	15.25	257.1

TABLE X. PIMA CLAY + ONE PERCENT MANURE.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.50	756.0	52.0	77.5
1	8.46	702.2	48.0	167.4
2	8.54	587.5	47.5	26.5
3	8.58	630.0	47.5	45.0
5	8.48	645.0	40.0	120.0
8	8.42	735.6	45.6	138.5
12	8.36	1100.0	55.3	400.2
20	8.40	1715.8	60.5	930.1

TABLE XI. PIMA CLAY + ONE PERCENT ALFALFA.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.14	1318.5	9.25	45.0
1	8.24	1080.0	9.25	156.5
2	8.15	1265.2	10.75	400.0
3	8.18	1387.5	10.60	554.0
5	8.20	1565.0	8.40	720.0
8	8.14	1555.0	10.40	720.0
12	8.12	2150.0	13.75	1372.7
20	8.21	3330.5	17.90	1800.0

TABLE XII. PIMA CLAY + ONE PERCENT HEGARI.

Time (Weeks)	pH	T.S.S. (P.P.M.)	PO ₄ (CO ₂ -Sol.) (P.P.M.)	NO ₃ (P.P.M.)
0	8.21	1095.0	7.00	47.4
1	8.39	660.0	12.90	125.0
2	8.49	610.0	12.50	10.0
3	8.55	605.0	12.75	0.0
5	8.51	567.5	10.00	0.0
8	8.44	710.0	10.75	0.0
12	8.56	662.5	12.35	15.0
20	8.47	820.0	16.88	225.0

Evidently, with the possible exception of alfalfa, the various organic materials had no significant effect on the pH of all three soils, which fact is in agreement with the findings of Stephenson (72) and Sackett, Ferguson and Ward (67). All three soils being calcareous in nature, it is to be expected that they are heavily buffered on the alkaline side as well as possessing a high degree of potential alkalinity. Hence it is conceivable that even appreciable amounts of carbonic acid will have negligible effects on the final reaction. At the same time it is realized that, while very accurate pH measurements are possible, they may not truly represent the conditions under which the plant is operating. Furthermore, a slight reduction in alkalinity may materially assist the plant in obtaining the different nutrient elements. Finally, the plant, being a living organism, is capable of adapting itself, creating physico-chemical and biological reactions which cannot easily be measured even with the most sensitive electrode.

There are only slight variations in soluble salts in the case of untreated soils, suggesting that microbiological activities proceed at a relatively slow rate. If organic matter be added, however, considerable changes are produced. Manure invariably causes a decrease during the first five weeks, to be followed by a gradual and continuous increase. The initial decrease is no doubt due to assimilation of nitrates

as will be pointed out later. In the case of alfalfa the lag period, if any, is relatively short, the soluble salts increasing rather rapidly, in close relation to increases in nitrates. Evidently, increases in soluble salts are produced by (a) mineralization of elements present in the organic matter, (b) solubility effects of CO_2 and organic acids, whereas decreases must be attributed to either absorption of these constituents by certain microorganisms or possibly by chemical reactions rendering certain salts insoluble. Hegari shows a marked reduction in all soils, which fact can be explained by the assimilation of nitrates and other elements whereby these constituents are converted into microbial protoplasm.

With respect to nitrates, it will be noticed that there is a gradual increase in this ion in untreated soils, pointing to the fact that complex organic compounds are being slowly converted to nitrates by certain organisms. It is a remarkable fact that manure with a relatively high nitrogen content, should show a lag phase with respect to nitrification. Evidently, the nitrogen is tied up in such a resistant form that the organisms concerned in the processes of ammonification and nitrification have to assimilate the nitrates initially present in the soil. Gradually, however, the nitrates increase, attaining high levels, especially in the case of the heavier soils. This slow rate of

nitrate accumulation in the case of manure must be regarded as a decided advantage since all nitrates are soluble and hence easily lost by leaching.

Alfalfa, on the other hand, undergoes rapid nitrification in all three soils, the largest amounts being produced in the case of Pima clay. Excessive amounts of nitrates are always subject to losses through leaching, which fact would make fairly heavy applications of alfalfa undesirable from this point of view. Hegari conforms to the well-known principle of nitrate-assimilation by microorganisms in the presence of excessive amounts of carbohydrate materials, this process lasting more than 20 weeks in the case of Gila Fine Sandy Loam and Gila Clay Loam, but evidently terminating after about 12 weeks in the case of Pima Clay. This fact is contrary to expectation, since one expects the various microbiological processes to be carried on at a greater rate in the case of the more sandy soils.

With all three soils, the application of manure markedly increased the amounts of CO_2 -soluble phosphates, even without any decomposition, whereas alfalfa and hegari, with the exception of the latter in the 20-week period for Gila Fine Sandy Loam, evidently had but slight effects over and above the untreated soils. While it is realized that the CO_2 -soluble phosphate is by no means a very accurate measure of its availability, one is nevertheless led to believe from

these data that the increases in phosphates are caused by that present in the materials added, and did not come from the mineral fraction of the soil. Breazeale and Burgess (10) have shown that, in the presence of CaCO_3 , CO_2 has no appreciable effect on the solubility of phosphates. Furthermore, inasmuch as phosphate solubility is largely a function of pH, these results seem to be in agreement with the fact that the various organic materials had no significant influence on pH. This problem will be discussed at greater length in connection with Neubauer studies to follow.

I. b. Percolation studies

It was felt that 1:5 extracts might not be a sufficiently sensitive method of measuring changes in the liquid phase as a result of microbiological activities. Hence percolation studies were resorted to, Gila Fine Sandy Loam being selected for this purpose. Duplicate 1500 gram samples of air-dry soil were placed in large percolation tubes with the same treatments as outlined for the 1:5 extracts. The soils were then leached with 1000 cc. portions of CO_2 -free distilled water after certain intervals of time and the percolates analysed for soluble salts (Bridge method), pH (hydrogen electrode), calcium and magnesium (soap titration method), potassium (colorimetric cobalt¹-nitrite method), bicarbonates (by titrating against $\text{n}/50 \text{ H}_2\text{SO}_4$, using methyl

orange as indicator) and nitrates (phenol disulfonic acid method). The results are recorded in Table XIII and some data is presented graphically in Plates 4, 5 and 6.

TABLE XIII. PERCOLATION STUDIES. EFFECT OF ORGANIC MATTER ON SOLUBLE SALTS, pH, CALCIUM, ETC. (GILA FINE SANDY LOAM)

Treatment	1 2 h o u r s				1 w e e k			
	Check, no Treatment	1 % Manure	1 % Alfalfa	1 % Hegari	Check, no Treatment	1 % Manure	1 % Alfalfa	1 % Hegari
T.S.S.(P.P.M.)	574.0	1516.0	2470.0	2019.0	361.0	1128.0	1630.0	2236.0
pH	8.42	8.30	7.48	7.80	9.03	8.92	8.22	8.12
Ca(P.P.M.)	135	375.0	840.0	660.0	82.5	262.0	660.4	435.0
Mg(P.P.M.)	11.0	19.0	37.1	37.0	7.5	11.5	15.0	15.0
K(P.P.M.)	44.0	80.0	213.3	128.5	23.0	83.6	307.7	30.7
HCO ₃ (P.P.M.)	634	976.0	1464.0	1220.0	402.0	1073.0	2488.0	1464.0
NO ₃ (P.P.M.)	203.8*	293.0*	886.0*	318.9*	59.6	59.6	70.6	57.2

Treatment	6 w e e k s				1 2 w e e k s			
	Check, no Treatment	1 % Manure	1 % Alfalfa	1 % Hegari	Check, no Treatment	1 % Manure	1 % Alfalfa	1 % Hegari
T.S.S.(P.P.M.)	415.0	240.0	570.5	273.0	273.0	203.3	485.0	216.5
pH	8.50	8.0	8.10	7.90	7.88	7.46	7.5	7.5
Ca(P.P.M.)	102.6	72.0	123.0	57.0	69.0	45.0	152.0	48.0
Mg(P.P.M.)	1.50	2.1	3.0	4.5	4.5	4.5	4.5	3.0
K(P.P.M.)	6.0	13.3	23.0	32.0	11.7	17.4	33.3	24.3
HCO ₃ (P.P.M.)	195.2	165.8	122.0	185.4	117.2	80.5	80.5	104.9
NO ₃ (P.P.M.)	92.4	22.0	283.8	15.4	46.9	24.0	176.0	tr.

*Includes ammonia-nitrogen.

PH.

PERCOLATION STUDIES
ON GILA FINE SANDY LOAM
EFFECT OF ORGANIC MATTER ON
PH AND CALCIUM

CALCIUM - P.P.M.

Tremendous increases in soluble salts, bicarbonates and calcium are obtained in cases where organic matter was added, especially in the first percolation, which took only twelve hours. The increases are greatest for alfalfa, to be followed by hegari, manure giving the smallest increases. It will be shown later that this is the order in which these three materials decompose. The pH shows a rise at first, but then drops considerably, especially in cases where organic matter was added. It is a remarkable fact that no significant differences could be found between treated and untreated soils after six weeks, suggesting that the greater part of the microbiological reactions was over by that time. It is evident from these data that decomposition processes are extremely rapid during the first few days, causing large quantities of calcium, and to a lesser extent, potassium and magnesium, to go into solution, chiefly as the bicarbonates. However, it appears that after six weeks had elapsed, the organic materials were incapable of supplying any more plant nutrients to the liquid phase than in the case of untreated soils.

These data are interesting from the standpoint of the fundamental difference between humid and arid regions. Whereas in the former the soil solution is constantly being depleted due to downward percolation of water, in the latter such losses are negligible, except perhaps under intensive

PERCOLATION STUDIES ON GILA FINE SANDY LOAM

EFFECT OF ORGANIC MATTER
ON BICARBONATES

$\text{HCO}_3 - \text{P.P.M.}$

TIME - WEEKS

PERCOLATION STUDIES ON GILA FINE SANDY LOAM

EFFECT OF ORGANIC MATTER
ON SOLUBLE SALTS

7.55 - P.M.

To 2470 at 12 hrs.

2200

2000

1800

1600

1400

1200

1000

800

600

400

200

0

HEGARI

MANURE

CALFALFA

CHECK

First values taken at 12 hrs.

0

2

4

6

8

10

12

TIME - WEEKS

irrigation practices. Furthermore, it is believed that CO_2 enters the liquid phase actively in humid regions, but has very slight chances of markedly affecting the equilibrium in the case of arid soils. In these regions, due to high temperatures, relatively low moisture with consequent negligible leaching effects, the odds are heavily against its entering actively into the liquid phase. We believe that the bulk is returned rapidly to the atmosphere without seriously affecting the more important soil processes. Likewise, although no data are available, we believe that CO_2 produced by microbiological processes plays an insignificant role in base-exchange reactions of arid soils, especially if the latter be alkaline-calcareous in nature.

II. Decomposition Studies

a. CO_2 evolution as an index to rates of decomposition

The data obtained with percolation studies suggested rapid decomposition of organic matter under these experimental conditions. Hence, quantitative investigations on rates of decomposition as measured by CO_2 production were undertaken.

Triplicate 100 gram samples of air-dry soil (Gila Fine Sandy Loam) were placed in pint milk bottles with the same treatments as described for 1:5 extracts and percolation studies. The moisture content was brought to the optimum, the flasks closed with stoppers fitted with tubes for

aspiration, incubated at 30° C., and the CO₂ allowed to accumulate (11). At the stated times, the flasks were connected in an aeration unit of the type described by Waksman and Fred (91) (see Figure A). The air drawn through the flasks was washed with 40 percent potassium hydroxide solution to remove CO₂ and then with water in order to keep the air well humidified and prevent desiccation of the soils. The CO₂ produced from the soils was determined volumetrically by precipitation with excess N/5 barium hydroxide, the excess base being titrated rapidly against N/5 oxalic acid, in the presence of phenolphthalein as indicator. In these determinations, the samples were aspirated in all cases for one hour and the results are expressed as milligrams CO₂ evolved daily in Table XIV and graphically in Plate 7.

FIG. - A

Aeration unit used in the
determination of Carbon Dioxide
produced from soil samples

TABLE XIV. EFFECT OF ORGANIC MATTER ON CO₂ PRODUCTION.
AVERAGE DAILY RATES (MILLIGRAMS CO₂
PRODUCED FROM 100 GRAMS (AIR-DRY)
GILA FINE SANDY LOAM - 30° C.

Time (Days)	Check	One % Manure	One % Alfalfa	One % Hegari
1	8.01	38.47	81.76	76.84
2	6.02	45.89	120.58	60.64
3	4.42	35.11	108.70	27.95
4	3.46	24.92	90.26	18.08
5	3.82	27.15	68.48	16.15
6	3.48	25.06	43.80	14.05
7	3.24	20.13	37.68	12.14
8	2.70	19.72	38.71	12.50
9	3.34	18.15	36.15	13.59
10	2.95	17.91	27.62	13.80
11	3.00	17.15	19.68	14.26
13	2.64	16.05	16.01	11.90
15	3.16	13.17	17.10	12.40
18	2.72	12.41	11.90	11.00
21	2.40	9.34	9.20	10.10
25	1.95	7.74	6.30	9.60
29	2.08	7.52	5.40	8.80
32	2.63	7.95	5.90	11.20
36	1.94	6.66	5.10	9.90
40	2.01	6.06	4.80	8.40
44	1.79	5.25	4.10	8.30
48	1.96	5.71	4.00	8.32
53	1.96	4.20	3.42	7.80
58	1.64	4.33	3.52	8.11
64	1.38	4.30	3.10	6.90
71	1.97	3.90	3.07	6.60
78	1.97	3.50	3.30	6.13
86	2.00	3.10	2.80	4.40
93	1.80	3.50	2.60	4.60

A study of the data obtained shows that tremendous quantities of CO₂ are liberated in cases where organic matter was added, the order being alfalfa, hegari, manure. In all cases the maximum production is reached at the end of the first or second day, the quantities falling rather rapidly after the third and fourth days, with the exception

Up to 120 at 2 days

Plate-7

that the sorghum maintains a fairly steady rate after the fourth day. These results are in general agreement with those of other investigators, with the exception that much larger amounts are produced, especially during the first few days, substantiating the fact previously referred to - viz., that microbiological activities proceed at a much more rapid rate in arid than in humid regions. The relative rates of decomposition are positively correlated with increases in calcium and bicarbonates in percolation studies. Furthermore, the C:N ratio does not seem to be the only deciding factor as far as rates of decomposition are concerned, but there is a relation between water soluble material and rates of decomposition. These facts are in agreement with results reported by Martin (50) and will be discussed at greater length in connection with fractionation studies to follow. The relatively high figures obtained from the sorghum are no doubt in part due to active nitrogen fixation by *Azotobacter* and related microorganisms, as will be shown later.

From the graph it is evident that by far the greater amounts of carbon dioxide are given off during the first week, the differences between treated and untreated soils being very slight after one month. These results confirm the conclusions arrived at from percolation studies - viz., that, whereas organic matter markedly increases the concen-

tration of especially calcium and bicarbonates, the differences become negligible after a month or more has elapsed. Again, 1:5 extracts showed that organic matter evidently has but slight, if any, effects on phosphate solubility. These results, together with Neubauer studies to be reported later, seem to indicate that the bulk of the CO_2 produced by microbial action does not remain in the soil, but is returned rapidly to the atmosphere, except in cases where leaching occurs.

Reference has been made to the fact that in the arid regions, due to relatively low moisture contents and high temperatures during the summer months, it is conceivable that CO_2 will be liberated to the atmosphere rather than remain in the liquid phase of the soil. Furthermore, it is advisable and often essential to allow approximately one month of decomposition before planting crops after green manuring and to a lesser extent applications of farm manure, inasmuch as plants are injured by actively decomposing organic matter. From our data it appears that at the end of such a time interval the organic matter is incapable of increasing the supply of nutrient elements in the liquid phase when the latter is subjected to constant depletion. Again, differences in CO_2 production at the end of this period are probably too small to cause any appreciable increases in rates of photosynthesis.

II. b. Decomposition of "pure" organic compounds in the presence of soil

Natural organic materials consist of a great many chemical complexes such as sugars, hemicelluloses, cellulose, lignin, proteins, etc., and a study of the relative rates at which some of the more abundant ones decompose in the absence of others is regarded as essential in order to understand their role in the formation and functions of soil humus. While it is realized that their relative rates of decomposition as "chemically pure" substances is no precise index as to their behavior when tied up in complex combinations in plants or manures, yet such data are regarded as important in the present investigation.

Duplicate 50 gram air-dry samples of Gila Fine Sandy Loam were placed in pint milk bottles with one percent applications of glucose, starch, cellulose (finely macerated filter paper) and lignin (prepared from corn cobs, Bureau of Chemistry and Soils 59). Moisture was brought to the optimum; the flasks closed with aspiration outfit as in (a), incubated at 30° C. and the CO₂ liberated determined volumetrically as described previously. The results are given in Table XV and graphically in Plate 8.

TABLE XV. DECOMPOSITION OF VARIOUS "PURE" ORGANIC COMPOUNDS IN THE PRESENCE OF SOIL. MILLIGRAMS CO₂ (TOTAL) PRODUCED FROM 50 GRAMS (AIR-DRY) GILA FINE SANDY LOAM AND ONE PERCENT APPLICATIONS OF GLUCOSE, STARCH, CELLULOSE AND LIGNIN (30° C.)

Time (Days)	Glucose	Starch	Cellulose	Lignin
1	21.34	8.62	6.25	17.00
2	119.02	19.95	12.63	31.63
3	237.12	30.60	21.03	45.27
4	364.42	48.52	33.61	53.42
5	414.76	56.44	57.11	61.00
6	446.33	60.88	69.21	72.00
7	459.97	65.54	77.83	79.48
8	469.54	70.49	84.21	86.18
10	484.06	77.53	95.71	95.88
12	493.97	83.57	104.07	102.26
14	507.28	94.07	113.97	108.86

If CO₂ production is taken as an index to rates of decomposition, then the order in which these substances undergo decomposition is: glucose, lignin, cellulose, starch.

A study of the data shows that large amounts of CO₂ are produced in the case of glucose as compared with the other complexes. Furthermore, as was found previously, the greatest amounts are liberated during the first few days. More significant, however, is the fact that lignin, while decomposing much more slowly than glucose, evidently undergoes more rapid transformations than either starch or cellulose.

These findings are in agreement with data reported by McGeorge and Greene (48). Smith and Brown (69) have also shown that certain soil fungi are capable of decomposing lignin almost as fast as xylans and cellulose. They

MILLIGRMS CO₂ PRODUCED FROM 50 GRMS.
GILA F.S. LOAM AND ONE % OF GLUCOSE,
STARCH, CELLULOSE, AND LIGNIN (30°C)

conclude that lignin does not possess bactericidal properties, and though it may decompose slowly, it gradually disappears from soils.

It is realized that, inasmuch as the compounds studied are essentially nitrogen-free, their relative rates of decomposition will be greatly influenced by the nitrate balance of the soil. Furthermore, glucose (and possibly starch, too) may be utilized as sources of energy by nitrogen-fixing organisms like *Azotobacter* and others, whereas cellulose and lignin are believed to be unavailable to such organisms. Consequently, the CO_2 evolved is no true index as to absolute rates of decomposition, although it is evident that simple sugars like glucose are much more readily broken down than more complex substances like cellulose or lignin.

II. c. Effect of moisture on the decomposition of organic matter

Moisture is probably the most important single limiting factor affecting the agricultural development of arid and semi-arid regions. This applies not only to final crop yields, but also to various physico-chemical and biological soil properties, the latter being associated primarily with microbiological activity and the humus balance. Consequently, a study of organic matter decomposition at different moisture contents is of fundamental importance in the present investigation, and carbon dioxide evolution appeared to

be the most sensitive method for such investigations.

The experimental technique consisted of placing 50 gram air-dry samples of Gila Fine Sandy Loam in pint milk bottles with one percent applications of alfalfa used in previous studies. The following moisture contents (expressed as percentage of the water-holding capacity, viz. 35) were selected: (1) air-dry, 3.06 percent, (2) 15 percent, (3) 35 percent, (4) 50 percent, (5) 75 percent and (6) 100 percent. Up to 50 percent of the water-holding capacity, the samples were mixed thoroughly after the required amounts of water had been added. The flasks were then closed with attachments for aspiration, incubated at 30° C. and the carbon dioxide determined volumetrically as described previously.

In order to maintain the different moisture contents the air, after being washed with 40 percent potassium hydroxide solution to remove carbon dioxide was passed slowly through different concentrations of sulfuric acid, prepared according to the vapor pressure data of Wilson (92) and Thomas (79). At the end of the experiment, moisture determinations were made on each sample, and it will be noticed from data in the last horizontal row of Table XVI that the different percentages had been fairly satisfactorily maintained. The results obtained in this investigation are recorded in Table XVI and graphically in Plates 9 (as

milligrams CO₂ accumulated over 16 days) and 10 (as rate of CO₂ production computed from the slope of the curves in Plate 10 at different time intervals).

TABLE XVI. INFLUENCE OF MOISTURE (AS PERCENT OF WATER-HOLDING CAPACITY) ON THE DECOMPOSITION OF ORGANIC MATTER. MILLIGRAMS CO₂ (ACCUMULATED) PRODUCED FROM 50 GRAMS (AIR-DRY) GILA FINE SANDY LOAM AND ONE PERCENT ALFALFA (30° C.).

Time (Days)	3.06% Moisture	15% Moisture	35% Moisture	50% Moisture	75% Moisture	100% Moisture
1	0.88	52.80	66.00	105.60	104.94	72.60
2	2.31	118.80	133.20	204.60	185.84	139.70
3	3.41	151.80	182.70	267.20	239.24	210.10
4	4.33	188.10	258.60	325.00	296.44	281.60
5	5.54	228.80	291.60	344.70	322.35	312.84
6	5.97	243.10	312.05	367.90	346.09	348.04
7	6.80	258.50	336.19	395.84	370.01	376.84
8	7.96	271.72	351.19	413.17	389.59	394.54
9	8.84	281.39	367.73	428.46	406.53	412.14
10	9.88	300.05	379.73	439.14	418.85	431.34
11	11.05	310.50	387.70	446.47	428.75	448.06
12	12.15	320.30	396.23	454.07	445.81	464.34
13	12.94	328.22	404.79	463.75	457.07	474.46
14	13.69	336.36	413.23	473.43	472.66	487.33
15	14.57	343.95	420.73	480.69	482.26	502.23
16	15.45	351.87	428.26	488.08	493.64	512.89
19	16.16	368.15	443.23	501.28	514.32	537.53
Final % Moisture	2.97	13.15	38.86	52.43	74.44	101.10

From the data it appears that negligible quantities of carbon dioxide are evolved from the air-dry soil. Most remarkable, however, is the fact that beyond the air-dry state, very small amounts of moisture give rise to large amounts of carbon dioxide, the quantities increasing up to

DECOMPOSITION OF ORGANIC MATTER AS A
FUNCTION OF MOISTURE. MGRMS CO₂ (TOTAL)
PRODUCED FROM 50 GRMS (AIR-DRY) GILA F.S.
LOAM AND 1% ALFALFA (30° C).

almost 75 percent, beyond which a decrease sets in. The results obtained for the first day (see Plate 10) represent a typical optimum curve with the largest amounts produced at 60 percent of the water-holding capacity. Beyond this time interval, however, the results no longer represent an optimum curve, probably due to local adaptations to moisture and aeration equilibria.

At the optimum and towards saturation, maximum production always occurs during the first and second days, but there appears to be a delayed maximum in the case of lower moisture contents, with the result that the relative rates are kept up at a higher level in the latter case (see Plate 10). Taking total quantities after 19 days, there is found a progressive increase in CO_2 production from 15 percent of the water-holding capacity up to complete saturation.

One factor of importance is the relatively large amounts of CO_2 liberated at 15 percent of the water-holding capacity, which value is considerably less than the wilting coefficient (see Plate 10). The later "constant" applies chiefly to higher plants and does not seem to have any great significance as far as microorganisms are concerned (It is realized that the use of the empirical factor 1.84 yields only an approximate value of the wilting coefficient). Large quantities of CO_2 are likewise liberated at complete saturation, no doubt chiefly by anaerobic microorganisms.

EFFECT OF MOISTURE ON RATES OF DECOMPOSITION AS COMPUTED FROM SLOPE OF CURVES IN PLATE 9 MGRMS CO₂ PRODUCED FROM 50 GRMS (AIR DRY) GILA F.S. LOAM AND ONE PER CENT ALFALFA (30°C)

Considerable difficulty is encountered in obtaining moisture percentages below the wilting coefficient, especially as far as uniform distribution is concerned. Furthermore, some trouble was experienced in controlling the relative humidity at the different contents by using varying concentrations of sulfuric acid. However, these limitations were in the main overcome, and the author feels that the data presented are a fairly reliable index of the facts. Satisfactory checks were obtained on duplicate samples.

Results reported by Woilny (93) and later by Waksman and co-workers (86) show that decomposition increases as the water content increases, the data being in very close agreement with that of the present investigation when compared on the basis of total percentage of moisture. It is unfortunate that these results should be expressed as total moisture rather than in terms of water-holding capacity, moisture equivalent or wilting percentage, especially since the latter two constants are not indicated in the results.

The fact that there appears to be a delayed maximum at the lower moisture contents and hence a more constant rate as time goes on suggests that over an extended period of time, the total amounts will not be greatly different from those produced at higher moisture contents.

As in previous studies reported on CO_2 production, the relative rates drop off rather abruptly beyond the second

and third days as shown in Plate 10. This is especially the case around the optimum moisture content, there being a more constant rate at the lower and higher percentages, relatively speaking. It is of course realized that variations in moisture bring about other repercussions like aeration, pH, etc., so that CO_2 production is not actually a true index as to the various processes going on. It appears, however, from these results that moisture is not such an important factor in the decomposition of organic matter as is usually assigned to it. The specific groups of organisms concerned appear to be capable of functioning very efficiently over a wide range of moisture contents.

The fact that considerable amounts of CO_2 are given off below the wilting coefficient and that maximum production occurs somewhat below the optimum moisture content (see Plate 10) suggests that the microflora, during their era of adaptation to moisture, have shifted the cardinal points to the left, i.e., we are dealing essentially with a xerophytic flora.

II. d. Effect of temperature on the decomposition of organic matter

Next to moisture, and in some cases perhaps of even greater biological significance, is the temperature factor, these two being the chief agencies determining plant distribution and soil fertility in general. The fundamental

importance of temperature is well illustrated in van 't Hoff's isotherm with respect to physico-chemical reactions, but the problem is much more complicated in physiological processes, especially when one attempts to study a heterogeneous microflora such as is found in the soil.

Wollny (93), Waksman and Gerretson (86) and others have shown that the rate at which organic matter decomposes increases with increase in temperature, with an optimum around 32° C. as found by carbon dioxide production from soils. No data seem to be available with respect to the arid and semi-arid regions; hence it was considered as an important aspect of the present investigation to study the relative rates of decomposition of organic matter at different temperatures. Carbon dioxide production was again selected as an index to rates of decomposition.

The experimental procedure was as follows: duplicate 50 gram (air-dry) samples of Gila Fine Sandy Loam were placed in pint milk bottles with one percent applications of alfalfa used in previous studies. After moisture had been adjusted to optimum, the flasks were closed with attachments for aspiration, and duplicate samples incubated at the following temperatures: 5° C., 11.5° C., approximately 22.5° C. (room temperature), 30° C. and 40° C., these different temperatures being maintained fairly constant by means of refrigerator and incubator adjustments.

As in previous experiments, the carbon dioxide was allowed to accumulate and then determined volumetrically as described previously. The results obtained are reported in Table XVII and in graphical form in Plates 11 (as total milligrams CO_2 accumulated over 16 days) and 12 (as rate of CO_2 production computed from the slope of the curves in Plate 11 at different time intervals).

TABLE XVII. INFLUENCE OF TEMPERATURE ON THE DECOMPOSITION OF ORGANIC MATTER. MILLIGRAMS CO_2 (ACCUMULATED) PRODUCED FROM 50 GRAMS (AIR-DRY) GILA FINE SANDY LOAM AND ONE PERCENT ALFALFA (OPTIMUM MOISTURE).

Time (Days)	5° C.	11.5° C.	22.5° C.	30° C.	40° C.
1	3.74	5.72	66.00	102.08	125.60
2	6.02	20.79	138.62	185.90	233.12
3	8.00	58.39	186.47	241.62	288.84
4	11.30	100.85	231.57	292.44	337.46
5	20.98	142.21	256.65	316.64	360.76
6	46.50	174.31	280.85	349.84	377.46
7	65.50	189.76	292.73	368.04	385.41
9	89.20	210.77	307.43	386.73	403.72
11	116.00	226.37	322.93	407.54	431.22
13	143.28	246.96	342.93	428.33	451.02
16	168.80	266.76	362.29	451.22	475.21

An examination of the data obtained indicates that there is a progressive increase in carbon dioxide production with increasing temperature, the curves being of the general logarithmic type. As is shown in Plate 12, the results obtained for the first day fit a typical optimum curve rather closely, but beyond this the curves flatten out in more or less the same fashion as found in the foregoing moisture

DECOMPOSITION OF ORGANIC MATTER AS A
FUNCTION OF TEMPERATURE, MGRMS. CO₂ (TOTAL)
PRODUCED FROM 50 GRMS. (AIR DRY) GILA F.S.
LOAM AND ONE PER CENT ALFALFA (OPTIMUM
MOISTURE).

investigations. When the curve representing rates for the first day is examined, it appears that maximum production does not occur even at 40° C. but somewhere in the neighborhood of 45° - 48° C. This is in distinct contrast with data reported by Wollny (93) where maximum production occurs at approximately 32° C.

For comparative purposes, one might cite results reported by Waksman (83) in this connection. A given amount of soil gave off the following amounts of CO₂, during three days at different temperatures:

<u>° C.</u>	<u>mg. of CO₂</u>
12.5	18.16
21.0	45.95
35.0	70.34

He further shows that in the case of organic matter in forest soils, most active decomposition of the fresh litter (birch leaves) takes place at 35° - 37° C. whereas the humus of the soil or of those residues which had already undergone decomposition for one year was attacked most rapidly at 50° - 60° C.

In the present investigation it was found that at the lower temperatures (5° and 11.5°), only small amounts of carbon dioxide are produced during the first few days, but the quantities gradually increase, the maximum being reached after seven or eight days. From room temperature up to 40° C., however, maximum production is invariably reached during

the first or second day.

It would appear from these results that, while temperature is evidently a more important factor than moisture in the decomposition of organic matter, microorganisms are capable of adaptations, hence to liberate carbon dioxide over a relatively wide range of temperature conditions. It would be interesting to study the effect of temperature at different moisture contents as is experienced under field conditions. While there is no doubt that decomposition processes are much more active during the hot summer months, considerable losses of organic matter may also occur during the winter months due to more favorable humidity conditions.

It was suggested that in the case of moisture, the microorganisms concerned in the transformation of organic matter have shifted the cardinal points in their life processes to the left - i.e., we are dealing with a xerophytic flora. From the data obtained in temperature studies the reverse process seems to occur - viz., the cardinal points have been shifted to the right, approximating a thermophilic flora. These two facts are regarded as extremely important in accounting for the rapid destruction of organic matter in arid and semi-arid regions.

II. e. Fractionations of different organic materials

A considerable amount of work has been done with respect to chemical changes in organic matter as a result of

of microbiological activities, especially since Waksman and co-workers have developed suitable methods of analysis. Again most of the researches have been confined largely to humid regions, so that considerable time and effort were spent in the present investigation with respect to this phase of the problem. The writer (56) with Theron and van Wyk (77) attempted fractionations of organic matter in the presence of soil, but there are several limitations yet to be overcome, some of which we hope to elucidate in the present investigation.

The first set of experiments was carried out with the organic materials as such, i.e., in the absence of any soil. Duplicate 15 gram air-dry samples of finely ground materials (the same as used previously) were weighed into small Erlenmeyer flasks, inoculated and brought to optimum moisture with a five percent suspension of Gila Fine Sandy Loam (approximately 200 percent moisture added), the flasks incubated at 30° C., the moisture being kept at the optimum. Fractionations were made after certain intervals of time according to the method outlined by Waksman and Stevens (88). Nitrogen was in all cases determined by the Kjeldahl method while reducing sugars were determined by the Shaffer-Hartman method (53). "Total organic matter" is designated as the residual material obtained by weighing after the required intervals of time had elapsed. All other constituents were

determined as described in the method referred to and determinations are expressed as percentages on the moisture-free basis. The results obtained are indicated in Tables XVIII, XIX, and XX and graphically in Plates 13, 14 and 15.

TABLE XVIII. CHEMICAL COMPOSITION OF MANURE AT DIFFERENT STAGES OF DECOMPOSITION. DATA EXPRESSED AS PERCENT ON THE MOISTURE-FREE BASIS.

Time (Weeks)	0	2	5	10
Ether soluble	2.72	2.16	3.38	1.42
Alcohol soluble	2.04	1.89	1.38	1.92
Cold water soluble	9.01	8.61	7.57	7.27
Hot water soluble	2.52	1.80	1.61	2.02
Hemicelluloses	14.18	12.79	10.57	9.09
Celluloses	11.34	11.20	8.76	7.34
Lignins	14.17	14.46	14.41	12.77
Crude Proteins	11.88	12.62	12.10	14.50
Ash	26.85	31.78	35.87	40.73
Percent material recovered	92.28	94.88	93.48	94.96
Percent material decomposed	0.0	17.17	25.33	26.00
Composition of cold water soluble fraction				
Organic matter	6.72	6.72	5.91	5.79
Crude Protein	2.38	2.34	2.10	1.33
Reducing sugars	0.58	0.64	0.33	0.41
Ash	2.29	1.89	1.66	1.48
Composition of hot water soluble fraction				
Organic matter	2.38	1.26	1.10	1.40
Crude Proteins	0.12	0.19	0.30	0.60
Reducing sugars	tr.	tr.	tr.	tr.
Ash	0.14	0.54	0.51	0.62

DECOMPOSITION STUDIES ON MANURE

TABLE XIX. CHEMICAL COMPOSITION OF ALFALFA AT DIFFERENT STAGES OF DECOMPOSITION. DATA EXPRESSED AS PERCENT ON THE MOISTURE-FREE BASIS.

Time (Weeks)	0	2	5	10
Ether soluble	1.96	2.13	2.60	1.67
Alcohol soluble	2.40	2.29	1.98	1.80
Cold water soluble	29.82	24.49	19.97	25.66
Hot water soluble	3.73	2.36	2.64	3.75
Hemicelluloses	11.29	8.88	7.98	8.48
Celluloses	13.38	19.36	16.48	16.91
Lignins	7.23	12.62	12.01	11.67
Crude proteins	19.27	17.00	15.28	17.87
Ash	10.03	19.76	21.76	24.69
Percent material recovered	93.46	98.31	90.52	99.42
Percent material decomposed	0.0	47.70	55.67	60.00
Composition of cold water soluble fraction				
Organic matter	24.44	14.73	10.58	13.36
Crude proteins	7.64	6.10	5.75	2.64
Reducing sugars	3.46	1.63	0.94	1.33
Ash	5.38	9.75	8.39	12.30
Composition of hot water soluble fraction				
Organic matter	3.46	1.63	1.91	2.72
Crude proteins	0.35	0.38	0.35	0.49
Reducing sugars	tr.	tr.	tr.	tr.
Ash	0.27	0.73	0.73	0.78

PLATE - 14
DECOMPOSITION STUDIES ON ALFALFA

Table XX. CHEMICAL COMPOSITION OF HEGARI SORGHUM AT DIFFERENT STAGES OF DECOMPOSITION. DATA EXPRESSED AS PERCENT ON THE MOISTURE-FREE BASIS.

Time (Weeks)	0	2	5	10
Ether soluble	2.37	0.94	1.21	0.76
Alcohol soluble	1.90	1.43	1.51	1.55
Cold water soluble	21.37	12.44	14.62	16.00
Hot water soluble	2.00	2.06	2.14	3.75
Hemicelluloses	20.44	20.32	17.99	17.42
Celluloses	21.47	23.20	19.26	16.82
Lignins	7.67	13.10	14.64	13.65
Crude proteins	2.94	2.43	5.57	7.06
Ash	13.53	21.47	22.36	28.69
Percent material recovered	89.26	92.07	94.73	100.50
Percent material decomposed	0.0	29.21	37.70	50.00
Composition of cold water soluble fraction				
Organic matter	17.45	7.91	10.81	11.74
Crude proteins	1.26	0.78	0.69	1.44
Reducing sugars	4.26	0.71	0.82	1.21
Ash	3.92	4.54	3.80	4.32
Composition of hot water soluble fraction				
Organic matter	1.49	1.28	1.38	2.78
Crude proteins	0.0	0.0	0.0	0.0
Reducing sugars	tr.	tr.	tr.	tr.
Ash	0.51	0.78	0.77	0.97

There is a rapid destruction of organic matter, the rates of decomposition being in accord with the evolution of CO₂ previously reported. These results are in agreement with general experience, as well as quantitative studies by the writer and others - viz., that organic matter undergoes rapid decomposition in arid regions, when sufficient moisture be present and especially under favorable temperature conditions. The average summer temperatures for Arizona are usually higher than 30° C., which fully justifies this choice of

DECOMPOSITION STUDIES ON HEGARI SORGUM

temperature. Evidently, the C:N ratio is not the only controlling factor affecting rates of decomposition, since hegari, with a wide ratio (118.4:1) decomposes much faster than manure, with a relatively narrow ratio (26.2:1). This is in accord with the findings of Waksman and particularly of Martin (50).

Reference has been made to the fact that in the case of manure, evidently the nitrogen is tied up in a rather stable or inactive form which must be regarded as a decided advantage. Furthermore, as suggested by Hutchings and Martin (31), the chemical composition of the various complexes is an important consideration: it will be noticed that the rates of decomposition bear a relation to the amount of water-soluble material present. Again, as found with CO₂ evolution, decomposition processes are tremendously rapid during the first few weeks, but tend to slow off rather abruptly. It is interesting to note that 50 percent of the alfalfa was decomposed after two weeks.

Obviously, variations (in all cases increases) in ash content are concentration effects as is evident from the plates. Attention is called to the relatively high ash content in the case of manure as compared with the two plant materials. The water-soluble fraction shows an interesting phenomenon: whereas there is a decrease in this constituent, especially in the case of alfalfa and hegari during the

first two weeks, the amount is in all cases kept up at a rather high level, quite distinct from results reported by Waksman and Tenney (90), where this fraction disappears very rapidly. An explanation for this fact is to be found in the decomposition of hemicelluloses, cellulose and even the lignin fraction. In humid regions these constituents, especially the lignin, are relatively resistant to decomposition and hence tend to accumulate; it appears that in our studies the rates of decomposition are much faster. It is common knowledge in Arizona that organic materials disappear rapidly and almost completely, and the reason for this is probably to be found in the fact that the microbial flora, characteristically high in actinomyces and spore-forming bacteria, are active decomposers of cellulose and lignin. Consequently, no accumulation of these compounds can take place.

The protein fraction likewise undergoes fairly rapid decomposition in the case of alfalfa and manure, whereas synthesis takes place in the case of hegari, evidently by means of nitrogen-fixing organisms like *Azotobacter*, et al. Arizona soils are characterized by their relatively high nitrogen-fixing capacity especially in the presence of available carbohydrate material such as hegari sorghum in this experiment. This fact accounts in part for the relatively rapid rate of decomposition of this material.

The general trends in these studies are in substantial agreement with those of other investigators (90), although it is evident that decomposition processes are carried on at a greater speed and that the more resistant fractions like cellulose and lignin are also relatively rapidly attacked. This fact no doubt accounts in part for the fundamental difference between arid and humid regions as far as accumulation of humus is concerned.

II. f. Fractionations of organic matter in the presence of soils

Waksman's excellent work (87) on the fractionation of organic matter at different stages of decomposition provides a method whereby such analyses can be carried out in soils, but there are various obstacles in the way, some of a purely mechanical, but others of a rather serious chemical nature. Thus Theron and van Wyk (77) found that ferric iron interferes with any reducing-sugar determinations, making it impossible to evaluate the carbohydrate fraction (hemicellulose and cellulose) otherwise than by difference. It was found that in soils containing about eight percent Fe_2O_3 , only 70 percent of reducing sugars could be recovered, the rest being oxidized by the iron. Waksman (83) suggests removal of iron and aluminum as the hydroxides before analysing for reducing sugars, but evidently does not allow for oxidation during hydrolysis.

Other factors, like the presence of relatively large amounts of carbonates together with mechanical difficulties encountered in filtration, impose decided limitations on the method when applied to soils. Yet it remains the final object to develop methods that would be suitable to follow the fate of the different organic constituents in actual presence of the soil in order to understand the various transformations that occur under field conditions. Considerable time and effort were therefore spent in this investigation in an endeavor to overcome some of the major difficulties already referred to.

In order to study the possible influence of calcium carbonate on organic matter decomposition, two soils were selected - viz., Gila Fine Sandy Loam (calcareous, 9.25 percent CaCO_3) and Tubac Clay Loam (A horizon, non-calcareous, containing only traces of carbonates). Duplicate 30 gram air-dry samples of each soil were weighed into glass tumblers, 10 grams of powdered (20 mesh) alfalfa (approximately half-bloom stage, but unfortunately not the same sample as used previously) added, the moisture brought to the optimum, and the tumblers incubated at 30°C. , the moisture being kept at the optimum.

After certain intervals of time, fractionations were made according to a modification of the method of Waksman and Stevens (87) as follows: the material was removed from

the incubator, dried at 50° C., and 20 gram samples (air-dry) taken for analysis. Cold water extractions were made by adding 150 cc. distilled water, extracting for 24 hours with occasional stirring, then filtering through weighed Whatman No. 1 paper by suction on Buchners, and analysing aliquot portions of the filtrate for water-soluble organic matter by evaporation. Considerable difficulty was encountered in filtration, since the extracts were badly dispersed, hence requiring much time for filtration. Furthermore, it was found difficult to remove the residue quantitatively from the filter paper for further extractions, although the errors introduced are believed to be small.

The residue, after drying at 50° C., was removed from the filter paper and treated with 2 percent HCl, hydrolysis being carried out in flowing steam for five hours. Filtration was made through the same filter papers and the filtrates analysed for reducing sugars which enables an estimation of the hemicellulose fraction. The residue was again dried at 50° C., removed from the filter papers, then treated with 20 cc. of 80 percent H₂SO₄ for 2-1/2 hours at room temperature, after which time it was diluted with 15 volumes of distilled water and hydrolysed for one hour at 15 pounds pressure. After cooling, the extracts were again filtered through the previously dried and weighed filter papers, the filtrates made up to volume and reducing sugars determined on

aliquot portions in order to estimate the amount of cellulose.

The residues were finally dried at 50° C., weighed, and aliquot portions analysed for carbon by means of the chromic acid method (18) while nitrogen was determined by the Kjeldahl method. This enables calculation of the lignin fraction. Organic matter on the original samples was determined by the chromic acid method, separate determinations and corrections being made for carbonate carbon.

Reference was made previously to the fact that ferric iron interferes with the determination of reducing sugars. Furthermore, there seems to be no suitable method whereby it is possible to either separate the iron or render it harmless as far as oxidation of the sugars during hydrolysis is concerned. However, it is a well-known fact that the arid soils of this region contain relatively small amounts of soluble iron, even where treated with strong acids. Iron determinations were made on the two soils (a) by boiling with two percent HCl for one hour, (b) with 80 percent H₂SO₄ in the cold followed by dilution and prolonged boiling, the iron being determined volumetrically by titrating against TiCl₃, using KCNS as indicator. The following results were obtained:

<u>Soil</u>	<u>Treatment</u>	<u>Percent Fe</u>
Gila Fine Sandy Loam	2% HCl	0.47
Gila Fine Sandy Loam	80% H ₂ SO ₄	0.69
Tubac Clay Loam	2% HCl	0.85
Tubac Clay Loam	80% H ₂ SO ₄	1.12

Evidently, only small quantities of iron become soluble, even when the soil is treated with concentrated acid.

In order to test the oxidizing effect of these quantities of iron, a known amount of glucose was added to each soil, treated with excess 2 percent HCl, boiled for two hours (keeping the volume constant by repeated additions of distilled water), filtered and the filtrates analysed for reducing sugars. In both soils, 95 to 98 percent of glucose could be recovered (Separate "blank" determinations were also made on each soil in order to account for any other oxidizing or reducing substances that may affect the determination of sugars. The results obtained, as far as the thiosulfate - tetrathionate oxidation reduction reaction is concerned, are negligible.).

From these data it appears then that iron is present in amounts too small to appreciably affect the results, which made it possible to fractionate the organic matter in the presence of soil according to the technique outlined. Total organic matter content for the zero-time interval is obtained by adding 25 percent to the original percentage of organic matter. All results are calculated as percentages of the total organic matter present at the various time

intervals on the moisture-free basis, the data being recorded in Tables XXI and XXII and graphically in Plates 16, 17 and 18.

TABLE XXI. CHEMICAL COMPOSITION OF ALFALFA AT DIFFERENT STAGES OF DECOMPOSITION IN THE PRESENCE OF GILA FINE SANDY LOAM. FRACTIONS EXPRESSED AS PERCENT OF TOTAL ORGANIC MATTER ON MOISTURE-FREE BASIS (30° C.).

Time (Weeks)	0	2	5	10
Total organic matter	25.85	10.08	9.00	8.57
Water soluble organic matter	26.60	26.20	19.56	16.42
Hemicelluloses	9.14	7.02	8.09	5.44
Celluloses	10.08	13.36	8.75	7.70
Lignins	12.23	16.33	25.75	18.63
Crude Proteins	20.94	36.44	34.40	32.50

TABLE XXII. CHEMICAL COMPOSITION OF ALFALFA AT DIFFERENT STAGES OF DECOMPOSITION IN THE PRESENCE OF TUBAC CLAY LOAM. FRACTIONS EXPRESSED AS PERCENT OF TOTAL ORGANIC MATTER ON MOISTURE-FREE BASIS (30° C.).

Time (Weeks)	0	2	5	10
Total organic matter	25.62	11.07	8.85	8.28
Water soluble organic matter	24.20	22.40	19.01	17.53
Hemicelluloses	11.16	9.02	11.30	9.10
Celluloses	10.80	12.70	11.30	6.52
Lignins	13.93	15.80	27.80	22.12
Crude Proteins	20.90	35.81	36.32	38.40

A study of the data obtained seems to indicate that decomposition processes follow the same general trend in both soils, suggesting that the presence of calcium carbonate has no marked influence in this respect. Furthermore,

DECOMPOSITION OF ALFALFA IN PRESENCE
OF GILA F.S. LOAM. FRACTIONS AS % OF
TOTAL ORGANIC MATTER (30°C)

DECOMPOSITION OF ALFALFA IN PRESENCE
OF TUBAC G. LOAM. FRACTIONS AS % OF
TOTAL ORGANIC MATTER (30°C.)

although the sample of alfalfa used was not the same as that of previous investigations in the absence of soil, it appears that the general trends of decomposition are very much alike (see Plate 18).

There is again found a very rapid destruction of total organic matter, 60 percent of the losses occurring during the first two weeks. Beyond this the rates slow down very decidedly. As was found previously, the water-soluble constituents, whilst undergoing rapid decomposition, are nevertheless maintained at a fairly high level, due to active transformation of the hemicellulose, cellulose, protein, as well as lignin fractions.

In both soils, the carbohydrate complex (hemicellulose and cellulose) is decomposed fairly rapidly, whereas there is a relative increase in the lignin and protein groups, somewhat more pronounced than was found in the absence of soil.

Plate 18 represents the actual rates at which the different fractions undergo decomposition both in the presence and absence of soil. In both cases the water soluble organic matter disappears rapidly, but is still kept up at a fairly high level. The hemicellulose fraction decomposes more rapidly than cellulose; both apparently are more rapidly transformed in the presence of soil, however.

As is evident from this graph the lignin group does

ACTUAL RATES OF DECOMPOSITION OF DIFFERENT ORGANIC FRACTIONS

PER CENT

32

28

24

20

16

12

8

4

0

ALFALFA INOCULATED WITH 4.5%
SUSPENSION OF GILA F.S. LOAM (30°C)ALFALFA (25%) IN PRESENCE OF
75% GILA F.S. LOAM (30°C)

WATER SOLUBLE ORG. MATTER

HEMICELLULOSE

CELLULOSE

LIGNIN

PROTEINS

WATER SOLUBLE ORG. MATTER

HEMICELLULOSE

CELLULOSE

LIGNIN

PROTEINS

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

0 2 5 10

TIME - WEEKS

undergo rather rapid decomposition, which confirms the conclusions arrived at from carbon dioxide measurements previously reported (see Plate 8). There appears to be a greater drop during the first two weeks in the presence of soil.

The proteins likewise are rapidly attacked, apparently somewhat slower in the presence of soil. In comparing these two sets of data, one must bear in mind that the samples of alfalfa were not the same and further that the presence of soil imposes some limitations on the analytical technique. Nevertheless, it appears as if the same trend of decomposition processes is carried on in both cases.

Perhaps of greater significance is the fact that there is no true accumulation of lignin, substantiating the conclusions arrived at from the decomposition of this constituent as measured by carbon dioxide production. Inasmuch as the ligno-protein complex is regarded as the "humus nucleus", its relatively rapid decomposition accounts in part for the rapid disappearance of organic matter from soils in the areas under consideration.

III. Neubauer Studies

The plant is the final criterion in all investigational work dealing with soil fertility and the Neubauer method suggested itself as the most suitable for such studies.

Gila Fine Sandy Loam was selected for this purpose. Duplicate 100 gram portions of air-dry soil were placed in enam-

eled dishes with 1 and 5 percent applications of each organic material. In order to study the effect of different stages of decomposition on the availability of phosphorus and potassium, four series were prepared, the first one being started in summer (July), whereas the other three were spread over a range of about five months. Moisture was in all cases maintained at the optimum and the dishes incubated at room temperature.

During November all four series were simultaneously subjected to the Neubauer treatment, using rye seedlings according to the standard technique. The seedlings were harvested 18 days after germination and analysed for phosphates, using the volumetric molybdate method, while potassium was determined by the colorimetric cobalti-nitrite method, care being taken to use a freshly prepared and standardized nitrite solution. The results obtained are given in Table XXIII and graphically in Plates 19 and 20.

TABLE XXIII. EFFECT OF ORGANIC MATTER ON AVAILABILITY OF PHOSPHATES AND POTASSIUM. MILLIGRAMS P_2O_5 AND K ABSORBED BY RYE SEEDLINGS IN NEUBAUER STUDIES (GILA FINE SANDY LOAM).

Treatment	Time of decomposition (weeks)	Percent germination	Mgs. P_2O_5 added with O.M.	Mgs. P_2O_5 absorbed	Mgs. K added with O.M.	Mgs. K absorbed
Sand blank (ave. 6)	0	88	0	29.24	0	13.00
Check, no treatment	0	77	0	31.75	0	25.01
1 percent manure	0	88	17.20	38.10	4.0	24.85
5 percent manure	0	89	86.00	36.70	20.0	28.00
1 percent alfalfa	0	71	5.60	27.80	0.8	18.80
5 percent alfalfa	0	77	28.00	29.10	4.0	26.00
1 percent hegari	0	76	2.50	31.50	0.9	21.50
5 percent hegari	0	84	12.50	29.60	4.5	23.80
Check, no treatment	4	65	0	28.60	0	18.80
1 percent manure	4	66	17.20	32.00	4.0	24.30
5 percent manure	4	79	86.00	40.20	20.0	28.40
1 percent alfalfa	4	85	5.60	32.60	0.80	28.50
5 percent alfalfa	4	90	28.00	35.88	4.00	36.10
1 percent hegari	4	61	2.50	26.40	0.90	20.10
5 percent hegari	4	91	12.50	35.25	4.50	32.90
Check, no treatment	11	75	0	33.80	0	20.00
1 percent manure	11	88	17.20	43.15	4.0	24.50
5 percent manure	11	87	86.00	41.75	20.0	28.10
1 percent alfalfa	11	86	5.60	35.00	0.80	26.00
5 percent alfalfa	11	84	28.00	41.10	4.00	28.90
1 percent hegari	11	83	2.50	30.70	0.90	28.50
5 percent hegari	11	92	12.50	38.50	4.50	36.80
Check, no treatment	20	56	0	28.00	0	20.00
1 percent manure	20	78	17.20	39.70	4.00	28.00
5 percent manure	20	78	86.00	47.50	20.00	34.50
1 percent alfalfa	20	85	5.60	29.70	0.80	28.75
5 percent alfalfa	20	88	28.00	38.20	4.00	41.40
1 percent hegari	20	91	2.50	37.20	0.90	28.40
5 percent hegari	20	95	12.50	35.00	4.50	38.40

FIG. B

General view of rye seedlings
grown in Neubauer studies
on the influence of organic
matter on plant growth

FIG. C

EFFECT OF DIFFERENT TREATMENTS ON RYE SEEDLINGS

- 1.-5 % ALFALFA followed by immediate planting
(Note injurious effects of freshly added organic matter)
- 2.-SAND BLANK
- 3.-CHECK - Soil with no treatment
- 4.-1% manure after 20 weeks of decomposition

Unfortunately, the average germination was very poor, although we feel that the results are still significant. The writer was informed by Mr. Breazeale and Mr. McGeorge of this laboratory that germination is invariably disappointing in most of the arid soils when used in Neubauer studies. Discarding germination percentages below 75 percent, it will be noticed that the soil is deficient in phosphates according to the Neubauer limits and that the organic matter, excepting in the case where no time was allowed for decomposition, invariably increased the amount of phosphates absorbed, the increases being greatest in those cases where the most time had elapsed for decomposition and where the largest amounts of organic matter were added. These results are in agreement with data of McGeorge and Greene from this laboratory (48).

The heavier applications did not, however, give a correspondingly greater absorption of phosphates. In cases where planting was done immediately following applications of the organic materials, the seedlings were markedly stunted, especially with respect to root development, the effects being most pronounced in the case of alfalfa and negari (see Fig. C). This fact accounts for the negative values obtained in these cases. With manure, increased phosphate assimilation took place although root development was also stunted. Manure also invariably gave the greatest

MILLIGRAMS OF P_2O_5 ABSORBED BY RYE SEEDLINGS

Soil - Gila Fine Sandy Loam

Black horizontal lines give value of total amount of P_2O_5 "available"

MILLIGRAMS P_2O_5 ABSORBED

110
100
90
80
70
60
50
40
30
20
10
0

SAND BLANK

CHECK Soil + no treatment

Soil + 1% manure

Soil + 5% manure

Soil + 1% Alfalfa

Soil + 5% Alfalfa

Soil + 1% Hegari

Soil + 5% Hegari

0 4 11 20

0 4 11 20

0 4 11 20

0 4 11 20

0 4 11 20

0 4 11 20

0 4 11 20

Time elapsed since organic matter was added to soil, to the time the seeds were planted
TIME - WEEKS

increases, with alfalfa second and hegari last.

Phosphate determinations were made on these three materials and it will be noticed that increased absorption by the seedlings follows the amounts added (rather closely.)

Furthermore, with the exception of the 20-week period for one percent hegari, the amount of P_2O_5 added and that present in the untreated soil are in excess of that absorbed by the seedlings. (It will be recalled that hegari also gave a considerable increase in phosphates in the case of Gila Fine Sandy Loam in the 1:5 studies.) This presents a problem: Did any phosphates come from the soil during microbiological decomposition processes, or are the increases due solely to that present in the added plant materials? Results obtained with 1:5 extracts showed that, with the possible exception of hegari in the case of Gila Fine Sandy Loam, decomposing organic matter evidently had negligible effects on phosphate solubility and we believe that the Neubauer results are in substantial agreement with this. Too often have investigators neglected the plant foods added with organic matter as such: palpably, unless the increases obtained be in excess of the plant foods added, one is not justified in concluding that the organic matter had caused any increase in phosphate availability from the soil. Furthermore, the same, and perhaps even greater increases could have been obtained by the direct application

MILLIGRAMS OF K ABSORBED BY RYE SEEDLINGS

Soil - Gila Fine Sandy Loam

Heavy horizontal lines
give value of total
amount of K "available"

TIME-WEEKS means: The time elapsed since organic matter was added to soil, to the time the rye seeds were planted.

of water-soluble phosphates. This point can hardly be over-emphasized inasmuch as it is the crucial test for organic matter as compared with artificial fertilizers.

The situation appears to be different with respect to absorption of potassium. In all cases, and more particularly with the heavier applications and longer incubation periods, the organic matter caused marked increases in potash availability. With one percent applications, the increases are in excess of the amounts added with the organic materials, showing that some potash must have come from the soil. Furthermore, the increases are related to the relative rates of decomposition, indicating that decomposing organic matter is capable of putting potassium into solution under these experimental conditions. It is believed that this increased solubility is brought about by way of base exchange in some such way as follows:

Probably small concentrations of CO_2 are capable of bringing about this reaction, which is rather remarkable since the soil in question is believed to be well supplied with potassium.

DISCUSSION

We may now discuss the general problem of organic matter decomposition in arid and semi-arid soils in the light of the foregoing experimental results and correlate them, if possible, with those of other investigators working in humid as well as arid regions.

Organic matter is a natural constituent of all agricultural soils and hence intimately associated with the numerous factors that have influenced the soil in the past and which determine its present state of fertility. Itself of complex nature, consisting of numerous types of organic compounds, it enters into physical, chemical and biological reactions, some of which are difficult, if not impossible, to study satisfactorily. The fact that it is the home of countless microorganisms completes a complicated picture which has through the ages interested thoughtful men.

Its origin, chemical composition and importance in nature have been recently well reviewed by Waksman (83) who is one of the most active workers in this field. The fundamental importance of microorganisms in keeping plant food elements in continuous circulation is probably the most important factor to be realized. But one must bear in mind that the advent of artificial fertilizers has in many respects upset the older concepts of soil fertility, a fact

which is not always sufficiently well appreciated.

In endeavoring to establish the significance of humus in arid and semi-arid regions, one is confronted by a lack of critical data concerning the problem. This is no doubt due to the fact that much of the land in these areas is marginal to cultivation, and as a consequence has not yet received the close experimental study as the soils of humid regions. However, sufficient data are available to establish the fundamental principles around which more detailed investigations can be built up in future.

Scientific soil research realizes the fundamental importance of climatic conditions in both the formation and fertility of soils. Generally speaking, the soils of arid and semi-arid regions are characterized by their relative stability and constructive genesis. This is due chiefly to relatively porous structure as a result of predominantly physical weathering and a high degree of base saturation, chiefly with calcium. Physically then, with the exception of the black alkali lands, these soils offer much less difficulty in cultivation than those of humid regions, where weathering agencies are chiefly chemical and destructive in nature. This being the case, it is obvious that organic matter will have totally different effects in the two regions. In the first place, humid soils contain larger total amounts due to climatic factors and plant development.

Jenny (33) has made an extensive study on the relation of temperature and moisture to the organic matter and nitrogen contents of soils in the U.S.A. and has shown conclusively:

- (a) within regions of constant moisture conditions the nitrogen and organic matter content of soils of medium texture decrease exponentially from north to south in relation to temperature. As a rule it can be said that for every fall of 10° C. in annual temperature, the average soil nitrogen and organic matter content increases two to three times.
- (b) Within regions of constant temperature, the nitrogen and organic matter of grassland soils increase logarithmically with increasing humidity factors.

The influence of temperature on nitrogen and organic matter temperature - relationships in the Eastern U.S.A. is illustrated by the following data assembled by Jenny (33):

<u>State</u>	<u>Number of Analyses</u>	<u>Approximate Annual Temperature</u>	<u>% N</u>	<u>% O.M. (C x 1.724)</u>
Maine	1	4 $^{\circ}$ C.	0.227	5.17
Pennsylvania	4	11	0.176	3.12
New York	4	11.2	0.116	2.78
New Jersey-	4	11.5	0.125	2.31
Virginia	7	15	0.075	1.36
N. Carolina	6	16	0.047	1.42
S. Carolina	4	17	0.028	0.92
Georgia	4	18.5	0.044	1.15
Florida	1	20	0.041	1.74

That the organic matter decreases with increasing aridity is shown by the following figures from the data of Sievers and Holtz for arid regions in the State of

Washington (68).

<u>Altitude</u> <u>(feet)</u>	<u>Annual</u> <u>Precipitation</u> <u>(inches)</u>	<u>Percent</u> <u>N</u> <u>in soil</u>	<u>C:N</u>	<u>% O.M.</u>
1050	7.5	0.054	12.7	0.68
1050	8.5	0.052	10.7	0.56
1400	10.0	0.083	12.1	1.00
1400	12.0	0.091	12.4	1.13
1565	12.5	0.060	11.00	0.66
1560	15.5	0.106	10.60	1.02
1525	16.00	0.082	13.4	1.09
1600	16.5	0.092	13.3	1.22
1800	17.0	0.108	13.4	1.45
2550	21.5	0.202	12.9	2.61

Hilgard and Jaffa (28), comparing the humus content of arid and humid regions, report the following data.

	<u>Number</u> <u>of Samples</u> <u>Analysed</u>	<u>Average</u> <u>% humus</u> <u>in soils</u>	<u>Average</u> <u>% N</u> <u>in humus</u>
Arid soils	18	0.75	15.87
Semi-arid soils	8	0.99	10.03
Moist soils	8	3.04	5.24

In the second place, whereas a satisfactory humus balance is regarded as essential for both the physical condition and fertility of humid regions, such does not appear to be the case in the arid sections. Theron and van Wyk of South Africa (77) have shown that profitable returns are obtained with artificial fertilizers, without the additions of organic matter. Similar results are reported by Thorne (80, 81) for the arid regions of this country. The writer (56) has also shown that, due to rapid decomposition processes, it is almost impossible to permanently increase the supply

of humus in sub-humid and semi-arid regions.

Finally, the nitrogen problem differs fundamentally in the two regions: humid soils are subjected to constant losses through leaching and abundant plant growth whereas the arid regions, although generally regarded as deficient in nitrogen, seem to maintain a satisfactory balance with the assistance of active nitrogen-fixation, both symbiotic and non-symbiotic. Furthermore, inasmuch as nitrogen is chiefly concerned with the vegetative development of plants, a low level is almost essential in arid regions, where high temperatures and lack of moisture predominate. Theron and van Wyk (77) conclude that green manures and rotations are not effective in increasing the nitrogen balance over an extended time. From results reported in the present work it appears that the application of manure, which is nitrified relatively slowly, will be more beneficial than green manures (see Plate 3 and Tables I - XII).

No physical investigations of the problem were undertaken, since the author considers them to be of secondary importance. Studies by Alway and Neller at Minnesota (2) show that the influence of ordinary applications of organic matter on the water-holding capacity and other factors related to moisture relationships are almost negligible. From Ohio experiments, Thorne (80, 81) likewise concludes that the physical benefits of organic matter have been over-

rated.

Attention is called to the possibility that during decomposition processes, the microorganisms themselves use large stores of water, hence may actually compete with crops during times of water stress. Again, due to its lyophilic nature as a colloid, organic matter may enhance deflocculation processes of alkaline soils so characteristic of arid soils. However, inasmuch as the arid soils are characterized by a relatively high concentration of soluble salts, this possibility may be materially offset. Conrad (14) is among the very few investigators that have given thought to this problem, but his results, obtained chiefly with crystalloidal, non-electrolytes like sugars, urea, etc., are not regarded as very significant. We feel that the colloidal aspects of the problem have not yet been sufficiently well investigated.

The influence of organic matter on the liquid phase of the soil was studied in the present investigation by means of water extracts and percolation methods. In aqueous extracts no decrease in pH could be found (see Plate 2), which can be explained by the fact that calcareous soils are heavily buffered on the alkaline side as well as possessing much reserve alkalinity. However, inasmuch as the growing plant is never in equilibrium with its environment, pH measurements (during the course of whose determinations

essentially an equilibrium reaction is assumed) might not actually represent the conditions under which the plant is operating. Organic matter, and particularly manure, is generally advocated for the amelioration of alkaline soil conditions, chiefly due to protective properties and biological transformation.

Its effect on soluble salts and nitrates depends primarily on its chemical composition, especially the C:N ratio. Thus in the presence of hegari, nitrates were found to disappear from the solution, whereas manure, and particularly alfalfa, are nitrified rapidly. (See Plates 1 and 3.) But more important perhaps is the fact that, apart from its own phosphorus content, decomposing organic matter evidently has no appreciable influence on phosphate availability (see Plate 2), probably the most acute problem in arid regions next to lack of moisture. From this aspect, the direct application of water-soluble phosphates almost completely overshadows the effects of organic matter.

Percolation studies revealed the fact that decomposition processes are very rapid. As is shown in Plate 4, the resulting carbon dioxide causes large amounts of calcium to go into solution, chiefly as the bicarbonate. However, leaching being almost negligible in the arid regions, these results are not regarded as very important, except that they do show the important distinction between arid and humid re-

gions. With the exception of nitrates and possibly potassium, it is believed that under these experimental conditions, organic matter has no marked influence on the liquid phase apart from the mineral elements that it contains.

In this connection recent work by McGeorge and Greene (48) on sulfur oxidation has shown that sulfur might well be regarded as a suitable substitute for organic matter. The analysis of aqueous extracts together with percolation studies by these two authors showed that (a) sulfur markedly improves the physical condition of soils by means of its conversion to sulfuric acid by certain bacteria, (b) it causes increased availability in phosphorus, potassium and calcium, at the same time reducing the pH to a remarkable extent, (c) that it compares more than favorably with organic matter with respect to plant growth as evidenced by the Neubauer method and (d) that it supplies a more constant rate of carbon dioxide production than organic matter. It appears from these results, therefore, that applications of sulfur will be more beneficial than attempts to increase the humus supply of these soils.

Extensive studies on the decomposition of various organic materials were undertaken in view of the fact that little data are available for arid regions. Manure, alfalfa and hegarl were studied. Taking carbon dioxide evolution as an index to rates of decomposition in the presence of soil,

COMPARATIVE RATES OF DECOMPOSITION OF ORGANIC MATTER IN ARID AND HUMID REGIONS

their relative order is alfalfa, hegari, manure, as is shown in Plate 7. In general, the results obtained are in substantial agreement with those of Martin (50) and Waksman and Tenney (92), but there are two important exceptions. First, as is evident from Plate 21, it appears that for the arid regions, somewhat larger amounts of CO_2 are liberated than in humid regions. In comparing such results one must, of course, bear in mind that the comparison is a relative one. Furthermore, the fact that average temperatures in humid regions are generally much below 30° would seem to indicate that under field conditions, relative rates of decomposition would be higher for arid than for humid regions within suitable moisture ranges. This fact will become the more pronounced when one recalls that temperature was found to be a more important factor than moisture (see Plates 9 and 11).

Secondly, as was shown in Plate 7, maximum production of CO_2 invariably occurs during the first or second day, whereas Martin (50) found maximum production to be delayed up to the sixth day in certain cases. This fact again suggests rapid decomposition of organic materials under arid conditions, explaining in part the rapidity with which organic matter disappears from our soils.

Reference has been made in the fore-going discussion that, apart from its mineral constituents, organic matter evidently has no pronounced effects on the liquid phase.

It is believed that carbon dioxide produced by microbial activity is for the greater part returned rapidly to the atmosphere, hence incapable of seriously affecting the relatively stable conditions existing. One might cite some evidence in proof of the above statement: (a) Large amounts of CO_2 are liberated when organic materials are added to soils (see Plates 7, 9 and 11). (b) When nitrate assimilation takes place as is shown in Plate 3 for hegari, the soluble salts decrease likewise. Yet hegari produces large amounts of CO_2 when incorporated with the soil (Table XIV and Plate 7). Further, as is evident from Plates 1 and 3, increases in nitrates and soluble salts run almost parallel, suggesting that CO_2 produced by microorganisms does not enter the liquid phase and thereby increase the concentration of soluble salts - e.g. bicarbonates. (c) It was suggested by Dr. T. F. Buehrer that "salting out" of CO_2 might occur due to large amounts of soluble salts present (see Plate 1). (d) Relatively high temperatures together with lack of moisture would decidedly limit the extent to which CO_2 will enter the soil solution in arid regions.

That CO_2 is a limiting factor in photosynthesis of higher plants has been definitely shown by Lundegårdh (43, 44). While this suggests CO_2 fertilization of the air, the problem is complicated by many factors under field conditions. We believe that lack of moisture, alkalinity and

unavailability of phosphates are such severe limiting factors in arid regions that changes in CO_2 concentration of the air due to organic matter decomposition are of relatively little importance to plant growth.

Experiments on rates of decomposition of various organic complexes like glucose, starch, cellulose and lignin when incorporated with a soil show that cellulose and lignin are decomposed fairly rapidly (Plate 8). It is, of course, realized that CO_2 production is not a true index of the relative rates of decomposition, since these compounds are essentially nitrogen-free. Nevertheless, the fundamental fact was established (Plates 8, 18) that lignin, generally regarded as the principal constituent of the "humus-nucleus", does not accumulate under our conditions, but is decomposed fairly rapidly, chiefly by actinomyces. Furthermore, we may assume that lignin is much more unstable under alkaline than under acid conditions. In view of the fact that the soils of arid and semi-arid regions are usually on the alkaline side of neutrality, conditions are more favorable for its decomposition.

Moisture must be regarded as the most important limiting factor determining the agricultural value of arid and semi-arid regions. Its influence on the decomposition of organic matter was studied in the present investigation by means of CO_2 evolution from soils (Plates 9 and 10). It was

definitely shown that, while the largest amounts of CO_2 are liberated at the optimum moisture content, great quantities are also evolved above and below this percentage. Particular attention is called to the fact that appreciable quantities are liberated even below the wilting coefficient (see curve representing 15 percent of water-holding capacity, Plate 9).

It is suggested that the microorganisms concerned in the decomposition processes, having been subjected to low moisture contents during many ages, have shifted the cardinal points in their life processes to the left, i.e. we are dealing with a xerophytic flora. Small amounts of moisture, far below even the wilting percentage, are sufficient to enable these organisms to decompose organic matter actively. Furthermore, active decomposition (largely anaerobic, no doubt), occurs even at complete saturation, showing that the microorganisms are capable of adjusting themselves to variations in moisture content. It seems, moreover, that moisture is not such an important factor in the decomposition of organic matter as is generally believed. Wollny (93) and Waksman and Gerretson (86) have shown that decomposition processes increase with increase in moisture content, but a comparison of results is difficult when moisture is expressed not in terms of the wilting coefficient or other more significant constants, but as total percentage of the soil.

Next to moisture, and in some cases perhaps of even greater importance, is the temperature factor, these two being the most important considerations in any climatic concept. Investigations concerning the influence of temperature on the decomposition of organic matter as obtained by CO_2 evolution in the present study point to the fact that maximum production will occur at about 45°C . according to Plate 12. For humid regions, Wollny (93) found maximum production to occur around 32°C ., suggesting that, in the case of temperature, the cardinal points have been shifted to the right for our conditions, just the reverse as was suggested in the case of moisture.

This theory seems plausible, since the microorganisms operate for the greater part of the year at fairly high temperatures, 50°C . during the summer months being by no means infrequent. It further appears that, although rather sensitive to low temperature ranges, adaptations are again possible just as in the case of moisture. From Plate 11 it is evident that the rates at which decomposition occurs at lower temperatures are less than those at higher temperatures, but are kept up at a more constant level as time proceeds, due to a delayed maximum. Consequently, over an extended time, large amounts of CO_2 may be liberated at fairly low temperatures. A comparison of the curves obtained in temperature (Plate 11) and moisture (Plate 9) studies

suggests that the former is a more important factor when CO_2 production is used as an index to organic matter decomposition. This is in agreement with the work of Jenny (33) previously referred to. At the same time, however, the combined rather than individual effects of temperature and moisture determine the rate at which organic matter will undergo decomposition.

In the present work, detailed studies were undertaken on the fractionation of organic materials at different stages of decomposition both in the presence and absence of soil. When inoculated with a dilute suspension of soil, the results obtained are in general agreement with those of other investigators as will be seen from the following comparison between data reported by Waksman and Tenney (90) for humid regions and those obtained in the present study (Table XXIV). These comparisons should be regarded as relative due to differences in chemical composition of the materials used.

TABLE XXIV. COMPARISON OF RESULTS ON THE DECOMPOSITION OF ALFALFA IN ARID AND HUMID REGIONS. (PERCENT BASIS)

<u>Humid Regions</u>					
Waksman and Tenney (New Jersey) (90)					
Chemical constituent	Original plant material	After days of decomposition			
		27	68	205	405
Total material	100.0	70.00	58.40	45.80	38.50
Ether soluble	2.75	-----	1.90	1.71	0.90
Cold water soluble	12.44	12.55	11.08	9.16	11.50
Hot water soluble	4.80	5.13	7.13	6.50	6.34
Hemicelluloses	8.52	6.24	6.39	7.29	8.22
Celluloses	26.71	22.63	16.48	15.15	15.90
Lignins	10.78	15.12	14.85	18.37	16.08
Crude proteins	8.13	8.43	7.31	10.31	9.18
Ash	10.30	-----	-----	23.42	24.88

<u>Arid Regions</u>				
Oberholzer (Arizona, present study)				
Chemical constituent	Original plant material	After days of decomposition		
		14	35	70
Total material	100.0	52.3	44.33	40.00
Ether soluble	1.96	2.13	2.60	1.67
Cold water soluble	29.82	24.49	19.97	25.66
Hot water soluble	3.73	2.36	2.64	3.75
Hemicelluloses	11.29	8.88	7.98	8.48
Celluloses	13.38	19.36	16.43	16.91
Lignins	7.23	12.62	12.01	11.67
Crude proteins	19.27	17.00	15.28	17.87
Ash	10.03	19.76	21.76	24.69

DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF ALFALFA IN ARID AND HUMID REGIONS

A - HUMID WARIMAN & TENNEY, NEW JERSEY

B. ARID - OBERHOLZER, ARIZONA

TIME - DAYS

It appears from these figures that organic matter disappears more rapidly under our conditions than in humid sections. Cellulose seems to be more resistant in arid regions according to the data reported while the other fractions show the same general trend. If one compares the results of non-leguminous materials (data reported by Waksman and Tenney (30) and those of the present study), the following differences show up. (1) Organic matter disappears more rapidly from arid than from humid regions. (Compare with previous CO_2 discussions.) (2) The water-soluble fraction, although subjected to vigorous decomposition, especially during the first few weeks, is maintained at a fairly high level in arid soils, but disappears to a large extent in humid regions. The reason for this phenomenon is to be found not in a slower rate of decomposition of the water-soluble fraction in our experiments, but rather in more active decomposition of the hemicelluloses, celluloses, lignins and proteins (see Plate 22).

With respect to the fractionation of organic matter at different stages of decomposition as well as the fate of the specific constituents as a result of microbial transformation, one must bear in mind that the method employed is open to some criticism. In the first place, determinations of water-soluble and alcohol soluble fractions are at best only semi-quantitative due to time factors. Furthermore, it was

found in the present study that during the cold water extraction, active decomposition takes place, making it necessary to sterilize the extracts by means of toluene. Finally, the writer does not agree with Waksman that the various organic constituents are decomposed in more or less water-tight compartments. The very minute that microbiological activities start, the original water soluble fraction loses its identity due to simultaneous decomposition of other fractions like proteins, etc. Furthermore, it is believed that the water-soluble fraction does not represent a true solution, but that part of it is in colloidal solution. The writer is not disposed to under-estimate the valuable work done by Waksman and co-workers on soil organic matter; rather is it his aim to offer constructive criticisms that would tend to further our knowledge in this matter.

Various difficulties are encountered when one attempts to fractionate organic matter in the actual presence of an excess of soil, but the author feels that he was able to obviate the more important limitations. Generally speaking, as is shown in Plates 14, 16 and 17, the trend of decomposition is essentially the same as found for organic materials as such. However, there appears to be a more rapid attack of the carbohydrate fraction, with a consequent more pronounced relative accumulation of the lignin-protein group in the presence of soils. When actual rates of decomposition

are compared, however, it is found (Plate 18) that they almost duplicate those obtained with organic materials that decompose in the absence of soil.

One fact stands out very clearly in relation to all decomposition studies, viz., the rapid rate at which organic materials undergo decomposition. It was pointed out previously that it is difficult if not impossible to permanently increase the amount of organic matter in soils of the arid regions due to its rapidity of decomposition, and it might not be entirely out of place to enumerate briefly the factors responsible for this phenomenon.

(a) The soils of arid and semi-arid regions are characterized by their great deficiency of humus. Consequently, any additions of organic matter markedly upset the biological equilibrium due to the additional supply of energy material. It is conceivable that under such conditions, this added material will be used up very rapidly.

(b) Studies on ammonification, nitrification, nitrogen fixation and carbon dioxide evolution show that the microflora is extremely active, microbiological rates being greater than those of cool and moist climates.

(c) The fact that decomposition processes are carried on over a wide range of moisture and temperature conditions have been conclusively shown in this investigation (see Plates 9 and 11). Specific attention is called to the fact that traces

of moisture, presumably below the wilting percentage, give rise to appreciable amounts of CO_2 , whereas increases in temperature markedly enhance the rates of decomposition. A combination of these two factors is regarded as very important in accounting for the rapid disappearance of organic matter from our soils.

(d) It has been shown conclusively in this investigation (see Plates 8, 18 and 22) that lignin, probably the most important constituent of humus, does not seem to accumulate, but disappears rather rapidly. It is suggested that the high numbers of actinomyces so characteristic of most arid soils are the chief organisms concerned in its decomposition.

(e) When organic matter undergoes decomposition, carbon dioxide, nitric acid and organic acids are the chief products of metabolism. If the process be carried out under alkaline conditions, these acidic metabolic products are immediately neutralized, and hence removed from the sphere of action. Consequently, in terms of the Mass Law, the reactions are bound to proceed to the right and approach completion, especially under favorable temperature conditions. This is essentially the situation in arid and semi-arid regions, where high temperatures and alkaline soil reactions predominate.

Neubauer investigations were carried out in an endeavor

to introduce the plant as "referee" as far as organic matter is concerned. Rye seedlings were grown in the presence of different types and amounts of organic matter at various stages of decomposition, the general appearance, together with absorption of phosphates and potassium, being used as criteria. It was found that actively decomposing organic matter inhibits the healthy growth of seedlings causing a marked stunting, particularly of the root systems (see Figure A). These harmful effects disappeared, however, after approximately one month of decomposition had elapsed. On the whole, the seedlings appeared to be more healthy and vigorous when grown in the presence of well-decomposed organic matter, particularly in the case of manure.

More important, however, is the absorption of phosphorus and potassium. It was found that decomposing organic matter is incapable of increasing the availability of phosphates over and above that which the organic matter contains as such, the increased absorption being in direct relation to the amounts present in the different materials added. (See Plate 19.) This must be regarded as a serious consideration, since the soils of arid regions are characterized by their deficiency of available phosphates. This gap, however, may be filled by the application of phosphatic fertilizers³, which find extensive use in arable farming. In these regions, lack of moisture and available phosphates

together with generally alkaline soil conditions completely overshadow the beneficial effects of organic matter.

In contrast to its effects on soil phosphates, organic matter markedly increases the availability of potassium (see Plate 20), almost in direct relation to its rate of decomposition, suggesting that the process is essentially related to base exchange. However, the soils in drier regions are usually well supplied with potassium, so that this fact cannot be regarded as very significant. Furthermore, inexpensive and efficient potassic fertilizers are probably more economical in cases of potash deficiency.

The Neubauer method, while the best biological index to soil fertility in short-range experimental work, offers only at best a very incomplete picture of soil fertility and plant growth. Plants differ in their response to environmental conditions at different stages of growth, and the author feels that altogether too many conclusions have been based solely on the response of seedlings. In most cases, crop production entails the entire life cycle of the plant; consequently, field trials carried out over a number of years should have more weight than seedling investigations conducted in laboratories mostly under highly artificial conditions.

In this connection, a theoretical consideration of the occurrence and importance of growth accessory substances or so-called "auximones" may not be entirely out of place.

Bottomley (8), Mockeridge (52), Breazeale (9) and other investigators hold that there are certain substances, essentially organic in nature, which stimulate the growth of higher plants. This is regarded as a strong argument in favor of maintaining or increasing the supply of soil organic matter, since these growth promoting substances are believed to originate from the decomposition of humus.

However attractive this theory may appear, it is still weak in many respects. In the first place, conflicting evidence has been produced by different investigators (15, 16). Secondly, most observations have been confined solely to seedling responses, some of which, as in the case of citrus (9), are bound to be abnormal, due to a lack of root hairs and possible symbiosis with mycorrhiza fungi or other organisms. Thirdly, it is difficult to grow plants under sterile conditions, thereby eliminating the direct and indirect influence of microorganisms. Fourthly, failure to account, in some cases, for the mineral elements present in such organic extracts, and the further fact that water soluble organic matter may contain nutrient elements in a more available form or traces of elements required in very small amounts, e.g. copper, manganese, zinc, boron, etc. Finally, most responses have been obtained with sand and water cultures, which at best give only a relative picture of plant growth in relation to soil fertility.

The writer is fully aware of the complicated nature of this problem, together with its potential significance and importance. He also realizes the fact that, apart from the mineral elements required for healthy growth, plants also require the presence of special substances as was shown recently by the discovery of the first plant hormone (78). Furthermore, evidence has been produced by Subrahmanyam and his associates (32) and Virtanen and von Hausen (82) of the existence of growth accessory substances in the case of certain yeasts, but it yet has to be shown that higher plants, and more particularly those of economic importance, require an external source of such substances for normal development. The problem is extremely complicated and one that requires the fullest sympathy and cooperation of soil investigator and plant physiologist. In the absence of more conclusive evidence the writer does not believe that it is of sufficient importance to warrant a building-up of the humus supply of soils, especially in arid regions.

An attempt will be made to apply the results and principles arrived at in this investigation to the general agricultural situation, and particularly their economical and practical aspects. The writer has always held that there is an important although not clearly defined distinction between fertility and productivity of soils. Whereas the former deals primarily with intrinsic soil

properties, those dynamic relationships upon which man and, for that matter, all life, is forever dependent, the latter refers essentially to the crop producing power of a soil, and more particularly the economical aspect. Farming practices of today are being subjected more and more to the same erratic business principles governing the stock market, and with disastrous results. In many instances, this has led to complete violation of the laws governing supply and demand as is evidenced by huge surplusses with simultaneous world depressions and famine.

Amidst this state of confusion, the soil scientist must disentangle the various enterprises into an orderly arrangement, realizing all the while that permanent fertility and steady yields to cope with future needs rather than haphazard production for profit is his main task. Is agriculture at the cross roads, or are we merely experiencing a stage of rapid expansion as a result of brilliant scientific researches? Are we not rather badly in need of re-orientation, stabilization and in general appreciation of those facts that lie at the basis of human existence and happiness?

As far as crop yields are concerned, if the aim of increased production by any means be mere speculation or the urge for greater luxury, then the writer is opposed to such policies, because they mean exploitation of soil fertility, so important for generations to come. Likewise, if organic

matter be instrumental in furthering the above policy by producing increased yields, then we rule definitely against its application to soils. Only when the aim is the fostering of soil fertility and protection against depletion do we lend our support and advocate its application to soils.

Only in the closest association with plant growth does the term "soil fertility" attain any significance, and modern research workers tend to introduce the plant wherever possible or feasible. The plant is always the final criterion, but obviously the problem is tremendously complicated by a constellation of factors which constitute the climate, which again affects plant development. Yet there are hopeful signs of getting at the basis of those factors that determine plant growth, provided soil chemist and plant physiologist can manage to work in closer cooperation than has been the case in the past. This is of the utmost importance, since both types of investigators have the same final object, viz., the growing plant. The discovery of the first plant hormone in recent years has already revolutionized the science of botany; it remains to be seen whether this factor together with accessory growth promoting substances are in any way related to soil fertility or organic matter.

Obviously, soil fertility and organic matter are inseparably connected. The mere fact that plants grow in a soil means existence of humus and microorganisms due to plant

residues such as roots, stubble and the like. Evaluation of the role played by organic matter has been largely based on certain bulk determinations such as pH, plant nutrients and even crop yields. These are of value but are only phenotypic considerations - i.e., the outcome of certain reactions under one set of conditions. Thus for genotypic soil investigations - i.e., the sum total of all the potential and possible functions under definite sets of conditions are almost entirely lacking, hence the conflicting evidence produced by various investigators.

Too often have we resorted to the visible or bulk factors in basing our concepts, neglecting the fact that the soil is an organism, capable of response and other features characteristic of life. Yields, structure and the host of physical and chemical constants utilized today in studying and judging soils are but some of the possibilities which the specific structure realizes under different sets of conditions, without explaining the basis upon which these phenomena rest. Seen in this light, the role of organic matter will vary with soil type and environmental conditions. Furthermore, the genotypic role of this constituent will differ from its phenotypic: whereas the former refers to its intrinsic role in plant life, possibly accessory or special food substances, the latter deals largely with its bulk effect on plant growth and crop yields.

It appears to the writer that, apart from the concept of limiting factors already referred to, different soils require different levels of organic matter for maximum productivity, with the distinction that organic matter is seldom a direct limiting factor in plant growth. We have yet to appreciate that in nature, direct effects are rare, and that simple explanations invariably miss the truth. It must be admitted that at present we have no reliable way of studying these indirect relationships and that the problem becomes much more complicated when viewed in this light. It follows, also, that it is fundamentally wrong to question the importance of organic matter just because it does not reduce the pH of alkaline soils, or increase the supply of available phosphates. These are poor criteria, especially when one considers that the growing plant is never in equilibrium with its environment, hence operating at pH values which cannot be measured even with the most sensitive electrodes.

Reference has been made to the fact that, generally speaking, intensive agriculture demands a high level of organic matter and vice versa. This seems logical in view of climatic factors, because in humid regions, plant growth is more abundant and decomposition processes probably somewhat slower than in the sub-humid and arid regions. In the latter areas, moisture is by far the limiting factor, farming is generally of a rather extensive nature and a high level

of organic matter does not seem to be essential in maintaining fertility. But this does not mean that the small quantities of organic matter are not extremely important. The writer holds that crop residues such as roots, stubble, etc., coupled with active azofication and other autotrophic microbial processes suffice for the maintenance of a satisfactory level of organic matter to ensure maximum yields. Wherever possible, manure and other forms of organic matter should be added, but the farmer should not aim at building up the store of organic matter in arid regions.

SUMMARY AND CONCLUSIONS

1. Aqueous 1:5 extracts on three soils using three types of organic matter showed the following:
 - a. Decomposing organic matter has no significant influence on the pH of calcareous soils.
 - b. Over and above its own phosphorus content, organic matter does not affect the availability of phosphates to any appreciable extent.
 - c. Its influence on soluble salts and nitrates depends primarily on its chemical nature, especially the C:N ratio. The slow rate at which manure is nitrified is regarded as a distinct advantage.
2. Percolation studies led to the conclusion that during the first few weeks, active decomposition results in large increases of soluble salts, especially calcium bicarbonate. After six weeks had elapsed, however, the difference between treated and untreated soils is negligible.
3. Alfalfa, hegarí and manure decompose in the order mentioned when CO_2 production from soils is taken as an index to rates of decomposition. Larger amounts of CO_2 are produced than are reported for humid regions and maximum production always occurs during the first or second day.
4. Glucose, lignin, cellulose and starch undergo decomposition in the order mentioned when incorporated with a soil

and rates of decomposition estimated by CO_2 evolution.

Explanations are suggested for the relatively rapid rate at which lignin decomposes and attention called to the significance and importance of this phenomenon.

5. The rate at which organic matter decomposes increases with increasing moisture up to almost complete saturation. However, considerable losses occur even below the wilting coefficient and it is suggested that the microbial flora has shifted the cardinal points with respect to moisture to the left, approaching a xerophytic flora.
6. Decomposition of organic matter increases with temperature, the maximum being around 45°C . as found by CO_2 production from soils. Whilst sensitive to low temperatures, adaptation is possible, allowing microorganisms to function over a relatively wide range of temperature conditions. It is suggested that in the case of temperature, the cardinal points have been shifted to the right, approximating a thermophilic flora. It appears that temperature is a more important factor than moisture in the decomposition of organic matter, but obviously a combination of the two is the actual criterion.
7. The bulk of the CO_2 produced by microbial action does not remain in the soil, but is returned rapidly to the atmosphere, without seriously affecting the relatively stable conditions existing.

8. Fractionations of organic materials at different stages of decomposition show that in general the trend is the same as that reported by other investigators. But it appears that there is a more rapid disappearance, that the water soluble fraction is maintained at a higher level and that the lignin and protein complexes suffer appreciable losses by microorganisms.
9. In the presence of soil, organic matter undergoes essentially the same trend of transformation, with the exception that the carbohydrate fraction tends to disappear somewhat more rapidly. This results in a more pronounced relative accumulation of lignin and proteins.
10. Neubauer investigations showed that actively decomposing organic matter is injurious to the growth of seedlings. It further appears that organic matter affects the availability of phosphates only to the extent of its own content of phosphate but markedly increases the availability of potassium from the soil.

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