

INFLUENCE OF THE DECOMPOSITION OF ORGANIC MATERIALS
ON THE PHYSICAL AND CHEMICAL PROPERTIES
OF SOME ARIZONA SOILS

by

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INTRODUCTION

The importance of the organic-matter fraction in soil fertility was generally recognized at the time that agriculture first began to be considered as a science; a fact which many years of practical experience and, more recently, of scientific study has strongly emphasized. Organic materials affect the physical and chemical properties of the soil, and provide the food and energy for the microorganisms present in the soil.

In recent years the organic fraction of the soil has been considered in its various chemical, physical, and microbiological aspects by workers in the field of soil science. However, the great bulk of this work has come from agricultural workers in humid regions, naturally emphasizing the relationship of organic matter incorporations to the properties of the moist acid soils of these regions. Little attention has been paid to the various aspects of the organic matter problem in the highly alkaline, calcareous, and often saline soils of semi-arid regions. The reason for this lack of attention is probably self-evident when one considers that organic matter constitutes a rather large portion - as high as five percent or more - of the soils of the humid regions; and, by comparison, a very insignificant and usually neglected

fraction - generally less than one percent - of the soils of the semi-arid and arid regions.

The reason for the low organic-matter content of the soils of Arizona and other parts of the world having similar climatic conditions probably rests with the high temperatures prevailing in these areas most of the year; which, when sufficient moisture is present, causes an accelerated rate of decomposition of organic materials.

This fact is emphasized by Burgess (17) who states that "it has been found uneconomical to attempt to increase permanently the organic-matter content of irrigated soils to any large degree, due to the fact that decomposition processes, both biological and chemical, are extremely rapid, owing to high temperatures, optimum moisture conditions, and good aeration".

Moreover, there has been an inclination among soil investigators to assume that organic materials decompose more rapidly in alkaline soils than in acid soils - an impression that probably results from such studies as those of Potter and Snyder (47) and Darkis, et. al. (21) who found that liming of acid soils accelerates organic matter decomposition. As will be pointed out later, this assumption may not be entirely justified.

Since organic-matter has a desirable effect

upon the soil, such as increasing the water holding capacity, (4, 14), and the base exchange capacity (34, 36, 39), it would seem desirable to build up this constituent in the soil, if possible. However, many workers, including Jenny (30), Blair (7, 8), Fippin (25), Sprague (56), Sievers and Holtz (55), Alway (3), and Thatcher (60), have found that, even under good management and fertilizer treatments, continuous cropping tends toward a depletion of the organic-matter content of soils; and that it is not economical, therefore, to try to increase and maintain the organic-matter content of the soil above the amount usually present in the soil under natural conditions. Hence, it is probably not feasible to attempt to increase permanently the organic-matter content of Arizona soils much beyond the amount present under natural conditions.

In view of the comparatively small permanent residues of organic matter in Arizona soils it would not be logical to expect the beneficial effects attributed to this component of the soils of humid regions. Consequently, if organic-matter additions are to be justified, it will be due chiefly to the decomposition process itself, and not to the residue left in the soil after decomposition is complete. DeTurk (22) concluded as a result of intensive research on this subject that the increases in crop yields due to organic matter additions result largely from the reactions involved in active

organic matter decomposition, rather than from the mass of comparatively inert residues which persist in small and difficultly measurable amounts in the soil.

In the present investigation, therefore, it was thought desirable to determine what influence actively decomposing organic materials would have on the various soil properties of importance to soil fertility - such as pH, total soluble salt content, formation of nitrates, and the degree of aggregation, which affects the penetration of water into the soil.

The possible effect of organic matter decomposition on the reaction of Arizona soils is of particular interest, since the prevailing high pH values cause many plant food elements - such as phosphorus, potassium, manganese, and iron - to be insoluble and therefore difficultly available to plants (44). Naturally in any attempt to remedy this situation, the question arises as to whether actively decomposing organic matter will lower the pH of these soils; and, if so, how much.

The length of time that nitrates are tied up and how soon the nitrogen of leguminous green-manure crops or manures is released as nitrates, are questions of much importance in the organic-matter problem of this region, since a deficiency of nitrogen as well as of organic matter is one of the common characteristics of these soils (62).

Organic matter in its various forms is commonly used in this region in the reclamation of alkaline soils (18), since it not only increases the water holding capacity, but also facilitates the penetration of water in the soil. Because of this widespread use of organic matter in reclamation work to improve soil structure, it is of interest to determine how effective various organic materials are in causing aggregation of the soil, since McGeorge (37) has shown that a crumb structure of water-stable aggregates is the most suitable soil structure for plant growth.

The investigation which constitutes a basis for this thesis was planned to include a study of suitable methods of analysis for future work on organic-matter problems and a study of the changes which occur in the soil during organic matter decomposition under ideal, rigorously controlled conditions.

REVIEW OF THE LITERATURE

During recent years the study of soil organic matter and its decomposition has increased tremendously because of the recognized importance of organic materials in the fertility of the soil. It would be difficult in a paper of this length to mention even very briefly all of the literature pertaining to this subject, but fortunately that will not be necessary since Wakeman (64) has recently made an extensive review of this work and his 'resume' can be referred to for details. It will be of interest, however, to mention briefly a few of the papers that are applicable to the soils of Arizona and similar regions, and that relate directly to the problem studied in this investigation.

Oberholzer (42) studied the decomposition of organic materials in Arizona soils and found that the decomposition increased with increasing moisture contents up to saturation, and that there was even considerable decomposition when the moisture in the soil was below the wilting point. He also found that the rate of decomposition increases with the temperature up to forty-five degrees Centigrade. After comparing his data with the results of a similar experiment performed on acid soils by Waksman and Tenney (66), he decided that organic matter

disappears more rapidly under arid-irrigated conditions than in the humid parts of the United States. However, he does not show whether such rapid disappearances resulted from the differences inherent in the soils of the two regions or from climatic factors. He observed that lignin, which McGeorge (35) shows is probably the principal base exchange constituent of humus, does not accumulate in Arizona's soils, possibly because of the large number of actinomyces present in the soils of this area.

Both Oberholzer (42) and Roades (48) observed no significant change in the reaction of alkaline soils with organic matter decomposition. Salter (52) reported that organic matter has a buffering action that helps regulate the pH. In apparent contradiction to the above results, Conrad (20) in California found a lowering of the reaction of Yolo loam during the decomposition of urea and "nitrated" sucrose, although in the "nitrated" control the pH slowly increased. Breazeale and McGeorge (16) concluded that the pH of the soil was controlled almost entirely by the carbon dioxide produced when organic materials decompose.

Oberholzer (42) observed that decomposing organic materials markedly increase the availability of potassium in the soil. On the other^{hand,} he makes the following statement with regard to phosphorus - - "over and above its own phosphorus content, organic matter does not affect the availa-

bility of phosphates to an appreciable extent". Rhoades (48) found increases in soluble phosphorus as the result of organic-matter decomposition in alkaline soils; but, in agreement with Oberholzer's work, he concluded that the increases were largely caused by the phosphorus released from the organic materials themselves and not by increased solubility of native soil phosphorus.

Starkey (57), Martin (32), Rhoades (48), Scott (54), Newton and Daniloff (41), and others, have observed that in the early stages of decomposition of materials of high carbon-nitrogen ratio, such as wheat and rye straw, there is a depletion of soluble nitrogen in the soil. Bell (6) found this depression also occurring during initial decomposition of some legumes. This effect was formerly attributed to various causes; for example, to the addition of substances toxic to the nitrifying bacteria. However, Allison (2), Blair and Prince (9), and others, have shown very definitely that this decrease in nitrates is due to the stimulation of biological activities so that the microorganisms of the soil utilize the nitrate present. Miller, Smith, and Brown (38) reported decomposition studies which showed that the accumulation of nitrates correlated with the nitrogen content of the material added.

Finnell (24) working with the high plains soils of Oklahoma showed that crop residues incorporated into

the soil by plowing or listing apparently required about three years' time under natural conditions for them to reach a low enough carbon-nitrogen ratio for maximum nitrate accumulation.

The use of green manures has been advocated for a long time in order to build up the organic-matter content of the soil. Leguminous crops in particular have been declared by Blair (7), Thompson (61), and many workers to be well suited for use in keeping up the nitrogen supply of the soil. Sprague (56) found that the value of the various manures in respect to increases in crop production was closely correlated with the amount of nitrogen present.

Van Slyke (63) however, states that "the use of green manures in dry regions is not practicable without irrigation, since with insignificant moisture the vegetable matter decays with extreme slowness, leaving the soil filled with air spaces and promoting loss of water by evaporation". Pieters (45), too, concluded that green manuring is not generally advisable in the drier regions because of the desiccating effect of the undecomposed particles which tend to leave the soil open and loose, allowing it to dry out with excess rapidity. Allen (1) in India found that sufficiency of moisture is necessary to allow decomposition of the green plant material before planting the following crop in order to obtain good germination. In irrigated

districts he advises an irrigation of the field after the organic matter has been plowed under and before the succeeding crop is planted in order to start decomposition of the green manure.

Several investigators, (28,46,56,59) have shown that manuring and crop rotation practices have a beneficial effect on crop production, indicating that green manuring is practical provided sufficient moisture is present.

In recent years commercial inorganic fertilizers have been largely replacing the use of organic manures for fertilizers. Although these compounds are very effective in supplying the necessary plant food elements, they are not entirely satisfactory in supplanting the use of organic material. Russell (49, 50), observed that organic fertilizers were not as effective as organic materials in maintaining a proper soil tilth, and that they could not supply the carbon necessary for the growth and activity of the bacterial population of the soil. He states, moreover, that if quantity of organic matter is the desirable thing, the prospect of restoring or maintaining it at any relatively high level is very gloomy for the semi-arid farmer.

Bottomley (11, 12), Mockeridge (40), Breazeale (15), and other investigators have reported vitamin-like

growth-promoting substances in organic materials and manures which are not present in the inorganic soil fraction.

Bonner and Greene (10) found vitamin B₁ (thiamin) present in organic manure and green plant materials. In view of these investigations and the recent extensive use of vitamin B₁ as a growth-promoting substance for plants, it seems quite likely that this substance, as well as many other specific growth substances - such as auxin, biotin, ascorbic acid, and indol-acetic acid - may be present in organic fertilizers and green manures, and may consequently be important constituents to consider in the use of these materials.

Due to the complexity of both the soil and the organic materials, the decomposition process and its effect on the soil becomes extremely complicated. For this reason, it is felt that, even though much work has been done on the subject of soil organic matter, there is still much to be learned.

This investigation was designed, therefore, to study the effects of the decomposition of organic material on the soil properties with special reference to the particular conditions found in this part of the country. Although the work was started with the practical point of view in mind, it is hoped that the conclusions will be of such a nature that they can be applied more or less generally in the study of organic matter decomposition.

EXPERIMENTAL

Plan of Investigation

The purpose of this investigation was to allow organic materials to decompose in Arizona soils under rigorously controlled, optimum conditions, observing the effect of the decomposition products on the physical and chemical properties of the soils.

Three typical soils from the various agricultural regions of Arizona were selected. They were as follows: (a) Pima clay loam from Safford (taken from a farm fertilized yearly for the last ten years with manure at the rate of 12 tons per acre), (b) Gila sandy loam from the State Agricultural Experiment Farm at Mesa, and (c) Superstition sand from Yuma. In addition to these soils, a sample of Clarion silt loam from Iowa was used for comparative purposes. The soils were collected fresh from the field, screened through a 10-mesh sieve, and thoroughly mixed in order to insure a uniform sample for experimentation.

Two leguminous plant materials, sesbania and sour clover, and two non-legumes, hegari and Markton oats, were chosen for the experiment since they are typical of the plant materials commonly added in large amounts to Arizona soils. The plants were gathered just prior to maturity, dried in the shade, and ground to pass a 20-mesh

screen. They were then incorporated with 150 gram aliquots of the soils in glass tumblers at the rate of two percent and uniformly mixed. Enough distilled water was added to each tumbler to bring the soil up to optimum moisture content (approximately 60 percent of the water holding capacity). Check samples of the untreated soil were also incubated with the other samples. From time to time enough water was added to keep the samples at optimum moisture content.

Methods of Analysis

At periodic intervals duplicate samples of each soil treatment were removed from the incubator for analysis. The soil in each tumbler was thoroughly mixed and aliquots taken for a determination of pH, total salts, nitrate-nitrogen, total carbon, and particle aggregations.

Fifty-gram samples - on a dry weight basis - of the mixed soil were transferred to wide-mouthed bottles, 250 ml. of distilled water added, and the bottles shaken for twenty minutes on a mechanical shaker. The total soluble salt content of this suspension was determined with a portable conductivity bridge, the calculations for the salt content being based on the tables of King and Whitson (31). The pH determinations were made on this 1:5 soil-water suspension with a Beckman glass electrode pH meter.

The suspension was then filtered and the nitrates determined on the filtrate by the phenol di-sulfonic acid method (5). When necessary, the solutions were clarified and decolorized by Harper's cupric sulphate-calcium hydroxide method (27). Chlorides were removed as silver chloride by adding silver sulphate to the solution. The color comparisons were made with a Cenco Photometer.

The following method, similar to the Walkley-Black modification (67) of Schollenberger's dichromate titration method (53) was used for the total carbon determinations: A soil sample of from 1 to 3 grams - depending on the carbon content - was weighed into a 300 ml. Erlenmeyer flask and 10 ml. of normal potassium dichromate solution added. Twenty milliliters of concentrated sulfuric acid were then added, the flask shaken gently, and allowed to stand a few minutes to cool, after which 125 ml. of water were added. Five grams of sodium fluoride and 1 ml. of diphenylamine indicator were added, and the solution titrated with N/2 ferrous ammonium sulfate (made up in 3N sulphuric acid) until the violet color changed sharply to green. The ferrous ammonium sulfate was standardized every time it was used by titrating a known amount of the standard dichromate solution with it. The percentage of carbon in the soil (dry basis) was then calculated. One ml. of normal dichromate solution reduced its equivalent to 0.004 grams of carbon under the conditions of the titration.

The effect of the organic materials on the structure of the soil was deduced from a determination of the aggregation of the soil particles. An adaptation, proposed by Gerdel (26), of the Bouyoucos hydrometer method of mechanical analysis (13), was used for this purpose. The soil was put into Bouyoucos cylinders and left to stand overnight. The following morning the cylinders were shaken end over end for 20 times by hand, and the percentage of particles less than 0.05 mm. in diameter determined by taking a hydrometer reading at exactly 40 seconds after the cylinder was replaced on the table and the particles allowed to settle, proper corrections being made for temperature.

By comparing the percentage of particles less than 0.05 mm. in diameter in the organic-matter treated soil with the percentage present in the untreated check samples, the influence of the decomposition process on the water stable aggregates of the soil can be deduced.

In order that the effects of the various organic materials can be more readily understood, a partial analysis of the plant materials was made. Total carbon determinations were made by the dichromate titration method as explained previously, total nitrogen determinations by the Kjeldahl-Gunning method (5), and the carbon-nitrogen ratios were calculated. The cold and hot water, alcohol, and ether soluble fractions were determined according to the methods of Waksman and Stevens (65).

Calcium was determined by precipitating it as the oxalate and titrating the dissolved precipitate with standard potassium permanganate (5). The phosphorus determinations were made by precipitation of the phosphorus as ammonium phospho-molybdate, dissolving the precipitate in standard sodium hydroxide, and back titrating with standard hydrochloric acid (5). The results of these analyses were given in Table VI.

RESULTS

The results of the various analyses are given in Tables I-IV. It may be noted that the soils selected for the experiment varied widely in characteristics. Textures ranged from clay loams to pure sand; the carbon contents ranged from 0.04 percent in the Superstition sand to 2.02 percent in the Clarion silt loam. The reactions of the alkaline-calcareous soils were all above pH 8.0 and ranged from pH 8.46 in the Pima clay loam to 8.79 in the Gila sandy loam. The Clarion silt loam from Iowa had a pH of but 5.4 and represents an acid soil condition. The suspension percentages of the untreated samples were about the same, namely 36 to 42 percent, with the exception of the Superstition sand, in which only 6 percent of the soil particles were less than 0.05 mm. in size. The total soluble salt contents were low (from 312 to 598 p.p.m.) in all but the Pima clay loam which had a total soluble salt content of 2012 p.p.m. The initial nitrate-nitrogen contents ranged from 2.5 p.p.m. in the Superstition sand to 60 p.p.m. in the Clarion silt loam.

TABLE I. EFFECT OF THE DECOMPOSITION OF ORGANIC MATERIALS ON SOME PROPERTIES OF GILA SANDY LOAM.

TREATMENT:	TIME IN: DAYS:	% CARBON:	pH:	T.S.S. (p. p. m.):	NO ₃ -N (p. p. m.):	% PARTICLES ≤ 0.05 mm.
No treatment:	0	0.35	8.79	505	16.1	36
	3	0.33	8.78	422	13.1	36
	7	0.34	8.76	455	11.6	34
	15	0.33	8.80	420	14.8	35
	28	0.32	8.77	541	20.9	35
	49	0.32	8.73	445	27.2	35
	70	0.32	8.68	470	29.5	35
	133	0.31	8.68	532	44.3	33
Sesbania (2%)	0	1.26	7.89	1585	15.9	35
	3	1.01	8.23	1235	8.9	35
	7	0.86	8.47	1272	13.3	30
	15	0.83	8.34	1760	95.0	31
	28	0.81	8.12	2428	244.0	28
	49	0.78	8.02	2155	333.5	30
	70	0.73	7.99	2288	336.0	30
	133	0.71	7.80	2440	405.0	28
Sour Clover (2%)	0	1.08	7.76	2087	16.1	36
	3	0.86	8.14	1570	15.8	36
	7	0.72	8.63	1472	5.8	32
	15	0.64	8.44	1868	76.3	32
	28	0.61	8.12	2930	342.5	32
	49	0.58	8.03	2635	420.0	32
	70	0.54	7.99	2940	437.0	31
	133	0.54	7.89	3095	532.0	30
Hegari (2%)	0	1.29	7.88	1293	16.2	35
	3	1.10	7.86	1117	5.3	33
	7	1.00	8.27	818	0.6	25
	15	0.97	8.71	728	0.4	27
	28	0.82	8.65	820	0.3	25
	49	0.79	8.61	650	4.6	25
	70	0.70	8.60	748	12.1	24
	133	0.62	8.32	988	74.0	21
Markton Oats (2%)	0	1.24	7.98	942	16.0	35
	3	1.10	8.12	714	2.8	34
	7	1.02	8.30	660	0.5	25
	15	0.89	8.88	506	0.3	22
	28	0.73	8.74	582	1.0	20
	49	0.67	8.67	588	29.8	24
	70	0.63	8.64	632	35.4	25
	133	0.60	8.24	900	112.0	20

TABLE II. EFFECT OF THE DECOMPOSITION OF ORGANIC MATERIALS ON SOME PROPERTIES OF PIMA CLAY LOAM.

TREATMENT:	TIME IN: DAYS	% CARBON:	pH	T. S. S. :(p. p. m.)	NO ₃ -N :(p. p. m.)	% PARTICLES :< 0.05 mm.
No treatment	0	1.24	8.46	2012	52.0	42
	3	1.25	8.45	1808	50.4	42
	7	1.25	8.45	1960	58.4	39
	15	1.26	8.47	2040	55.8	38
	28	1.24	8.42	2078	90.5	38
	49	1.22	8.38	2110	94.8	38
	70	1.23	8.40	2160	116.0	39
	133	1.24	8.35	2330	148.5	37
Sesbania (2%)	0	2.12	7.88	3020	52.0	42
	3	1.91	8.05	2450	3.2	41
	7	1.82	8.18	2595	26.6	36
	15	1.72	8.11	3320	214.1	33
	28	1.67	8.01	3452	339.5	32
	49	1.64	7.92	3610	378.0	31
	70	1.57	7.90	3610	412.0	30
	133	1.57	7.92	4700	565.0	29
Sour Clover (2%)	0	2.02	7.85	3190	52.0	40
	3	1.82	8.08	2655	20.0	38
	7	1.68	8.31	2882	58.7	34
	15	1.60	8.14	3715	274.6	34
	28	1.58	8.02	3795	393.0	33
	49	1.56	7.95	2908	442.0	31
	70	1.48	7.97	4015	460.0	32
	133	1.45	7.91	4912	594.0	30
Hegari (2%)	0	2.14	7.95	2892	52.0	40
	3	1.95	8.00	2115	1.5	36
	7	1.87	8.16	2128	0.6	34
	15	1.76	8.52	2080	0.7	32
	28	1.64	8.49	2092	1.8	30
	49	1.62	8.36	2080	27.7	30
	70	1.54	8.43	2182	54.7	30
	133	1.51	8.22	2670	151.5	26
Markton Oats (2%)	0	2.18	8.06	2330	52.0	40
	3	2.05	8.09	1958	1.4	34
	7	1.96	8.33	1960	0.6	33
	15	1.87	8.60	1845	0.5	27
	28	1.70	8.58	1842	0.9	28
	49	1.63	8.48	1837	7.4	30
	70	1.49	8.43	2142	73.9	29
	133	1.48	8.31	2235	122.0	24

TABLE III. EFFECT OF THE DECOMPOSITION OF ORGANIC MATERIALS ON SOME PROPERTIES OF SUPERSTITION SAND.

TREATMENT:	TIME IN: DAYS	% CARBON:	pH	T. S. S. (P. P. M.):	NO ₃ -N (p. p. m.):	% PARTICLES < 0.05 mm.
No treatment	0	0.04	8.77	314	2.5	6
	3	0.02	8.76	210	1.2	6
	7	0.02	8.74	270	0.9	6
	15	0.02	8.77	250	1.4	5
	29	0.02	8.79	215	2.2	4
	50	0.02	8.76	272	3.4	4
	71	0.03	8.75	170	5.9	3
	133	0.02	8.82	195	5.8	3
Sesbania (2%)	0	0.86	7.12	1770	2.5	5
	3	0.80	8.01	1252	5.8	4
	7	0.63	8.86	1128	5.4	5
	15	0.57	8.89	1172	12.5	5
	29	0.53	8.50	1745	34.1	4
	50	0.48	8.14	1635	168.5	4
	71	0.46	8.12	1928	276.0	3
	33	0.34	7.95	2915	334.0	2
Sour Clover (2%)	0	0.80	7.26	2110	2.5	5
	3	0.75	7.56	1710	5.4	4
	7	0.47	8.90	1395	6.4	4
	15	0.38	9.03	1538	6.3	5
	29	0.32	8.96	1595	6.8	4
	50	0.28	8.51	1972	129.6	4
	71	0.27	8.36	2082	218.0	3
	133	0.25	8.17	2970	270.0	1
Hegari (2%)	0	0.89	7.48	1380	2.5	5
	3	0.85	7.73	872	2.2	4
	7	0.69	8.62	690	0.4	3
	15	0.65	8.61	692	0.4	2
	29	0.56	8.64	612	0.4	2
	50	0.48	8.48	628	1.5	1
	71	0.40	8.43	540	6.8	0
	133	0.32	8.42	610	25.2	0
Markton Oats (2%)	0	0.90	7.52	765	2.5	5
	3	0.86	7.80	632	1.9	4
	7	0.74	8.70	510	0.3	4
	15	0.68	8.64	482	0.4	2
	29	0.53	8.70	396	0.5	2
	50	0.42	8.54	518	15.3	1
	71	0.32	8.48	408	33.6	1
	133	0.27	8.45	592	51.9	0

TABLE IV. EFFECT OF THE DECOMPOSITION OF ORGANIC MATERIALS ON SOME PROPERTIES OF CLARION SILT LOAM

TREATMENT:	TIME IN: DAYS:	% CARBON:	pH	T. S. S. (p. p. m.)	NO ₃ -N (p. p. m.)	% PARTICLES < 0.05 mm.
No treatment:	0	2.02	5.40	598	60.0	38
	3	1.98	5.29	398	58.2	36
	7	1.86	5.30	590	58.9	33
	15	1.84	5.25	570	61.5	33
	29	1.89	5.22	648	91.5	34
	50	1.87	5.19	735	107.5	32
	71	1.87	5.04	818	105.5	31
	133	1.79	4.92	918	161.0	28
Sesbania (2%)	0	2.88	5.34	1432	60.0	39
	3	2.60	6.34	848	4.1	37
	7	2.52	7.00	920	0.9	34
	15	2.41	7.23	932	9.1	32
	29	2.36	7.07	900	13.7	28
	50	2.33	5.96	1608	164.5	25
	71	2.21	5.21	2055	300.0	21
	133	2.18	4.58	2845	509.0	19
Sour Clover (2%)	0	2.79	5.39	1592	60.0	40
	3	2.65	6.18	1305	46.9	39
	7	2.47	6.85	1162	16.8	33
	15	2.32	7.48	1128	6.8	32
	29	2.26	7.49	1050	8.0	31
	50	2.18	6.75	1695	54.5	25
	71	2.05	6.05	2048	218.0	27
	133	2.06	5.19	2950	440.0	26
Hegari (2%)	0	2.92	5.35	1123	60.0	38
	3	2.66	5.75	710	6.2	36
	7	2.54	6.71	602	0.7	32
	15	2.42	6.14	562	0.5	26
	29	2.30	5.99	408	0.9	23
	50	2.26	5.87	608	9.1	22
	71	2.15	5.34	952	71.4	19
	133	2.05	5.02	1315	163.0	14
Markton Oats (2%)	0	2.93	5.40	798	60.0	38
	3	2.62	5.86	462	3.7	35
	7	2.46	6.63	405	0.2	30
	15	2.39	6.12	392	0.6	22
	29	2.34	6.01	375	4.3	21
	50	2.21	5.53	658	60.5	18
	71	2.11	5.27	852	113.0	16
	133	2.04	4.94	1200	187.5	15

Rate of Decomposition

Curves showing the decreases in the carbon contents of the variously treated samples of Pima clay loam and Clarion silt loam during the period of incubation are shown in Figures 1 and 2. Graphs for only two of these soils are given because they are representative of the entire group, though differing in magnitude of the observed effect. It was thought desirable, for comparative purposes to include graphs of the acid Clarion soils and one of the alkaline-calcareous Arizona soils. These decomposition curves are typical and show that the rate of decomposition of the added carbonaceous materials was most rapid during the first two weeks of decomposition; after which a gradually decreasing amount of carbon was lost in a given period of time, so that even after 133 days' incubation all of the added carbonaceous material had not yet been completely oxidized to carbon dioxide and water.

It is evident from these curves, however, that the various organic materials decompose at different rates in a given soil and the rates also vary from soil to soil. In order that these relationships might be more evident, the data given in Table V were computed and show in terms of percentage of the carbon originally added to each soil, how much was lost at various times during the incubation

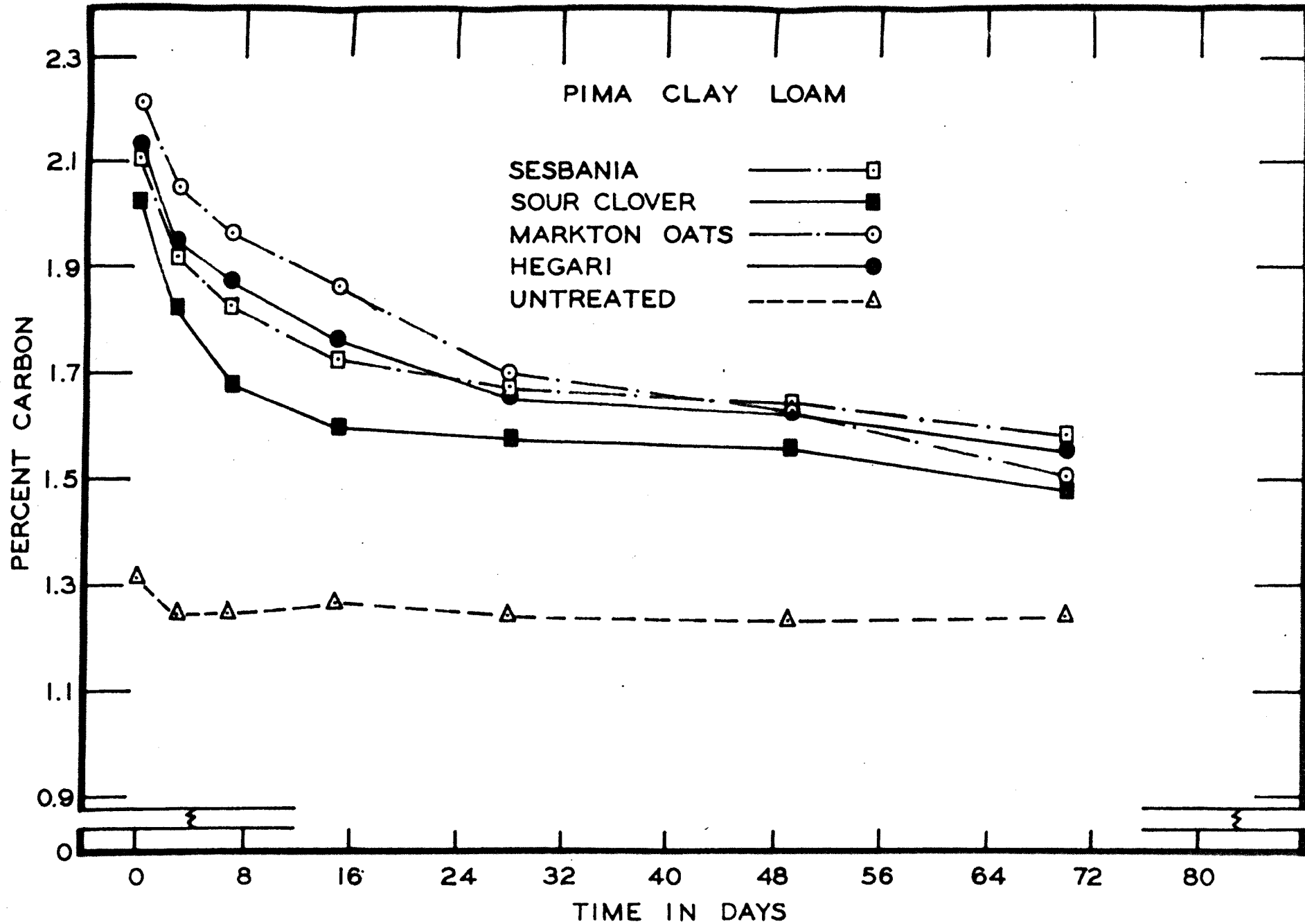


Fig. 1. Changes in carbon contents of samples of Pima clay loam during the decomposition of organic materials.

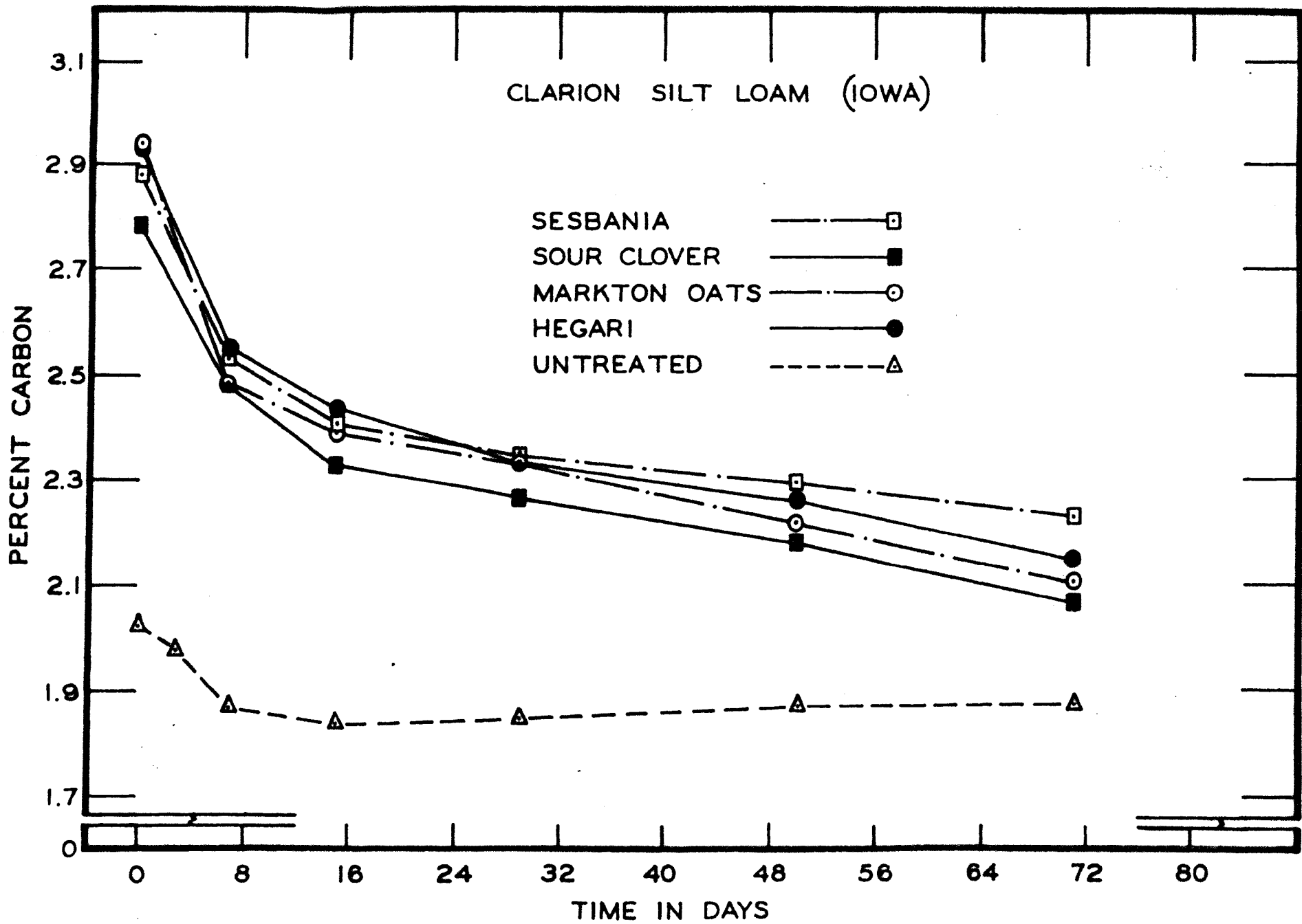


Fig. 2. Changes in carbon contents of samples of Clarion silt loam during the decomposition of organic materials.

TABLE V. CARBON LOSS WITH TIME IN VARIOUSLY TREATED SOILS.

Treatment	TIME DAYS	Gila sandy loam :		Pima clay loam :		Superstition sand :		Clarion silt loam	
		Gm. C/ 100 gm. soil	loss in: weight :	Gm. C/ 100 gm. soil	loss in: weight :	Gm. C/ 100 gm. soil	loss in: weight :	Gm. C/ 100 gm. soil	loss in: weight :
Sesbania	0	0.91	0	0.88	0	0.82	0	0.86	0
	15	0.48	47.2	0.48	45.5	0.57	30.5	0.59	54.6
	133	0.36	60.4	0.36	62.5	0.54	58.5	0.16	81.4
Sour Clover	0	0.73	0	0.78	0	0.76	0	0.77	0
	15	0.29	60.3	0.36	53.9	0.33	50.0	0.30	61.0
	133	0.19	74.0	0.21	73.1	0.25	67.2	0.04	94.9
Hegari	0	0.94	0	0.90	0	0.35	0	0.90	0
	15	0.62	34.0	0.52	42.2	0.65	23.6	0.40	55.6
	133	0.27	71.3	0.27	70.0	0.32	62.5	0.03	96.5
Markton oats	0	0.89	0	0.94	0	0.86	0	0.91	0
	15	0.54	39.3	0.63	33.0	0.68	20.9	0.37	59.4
	133	0.25	72.0	0.24	74.5	0.27	68.6	0.02	98.0

period. The 15-day period was chosen for the comparisons since at the end of this time the first rapid decomposition had ceased and comparisons made at this time would show whether or not the different organic materials differed in their initial rates of decomposition. The 133-day period was chosen since it was the last time interval after which analyses were made.

It will be noted that, at the end of both the 15 day and 133 day intervals, the decomposition of each of the organic materials used in this experiment was most rapid in the Clarion silt loam from Iowa and the least rapid in the Superstition sand. The decomposition rates in the Gila sandy loam and the Pima clay loam were almost identical.

The initial decomposition of the leguminous plant materials (sesbania and sour clover) was more rapid than that of the non-leguminous materials (hegari and Markton oats) in the alkaline-calcareous soils whereas in the acid Clarion silt loam, the rates were about equal. After 133 days of incubation, however, a greater percentage of the carbon originally added in the non-leguminous plant materials had been oxidized than of that added in the leguminous materials. Sour clover was found to be an exception to this, since in the alkaline-calcareous soils, the

amounts of this material decomposed in 133 days of incubation were approximately equivalent to the amounts of hegari and Markton oats decomposed in the same period.

Little difference was observed between the percentages of carbon lost after the different periods of incubation in any one soil treated with hegari and Markton oats. In all cases the sour clover lost more carbon than the sesbania.

Reaction Changes

The influence of the decomposition process on the reactions of the different soils used in this experiment may be noted from the appropriate column in tables I-IV and is also depicted in graphical form in figures 3 and 4. It is apparent that the addition of organic materials to soils may have a marked effect upon the pH value, not only initially but also during the course of the decomposition. In the three alkaline-calcareous soils, all of the organic materials caused an initial drop in the pH. The magnitude of the decrease was found to be related to the buffer capacity of the particular soil. Thus an average initial lowering of 0.5 pH unit occurred in the case of the Pima clay loam, 0.91 pH unit in the Gila sandy loam, and 1.42 pH units in the Superstition sand. It will also be noted that the leguminous plant materials caused a greater initial lowering than the non-legumes. Thus

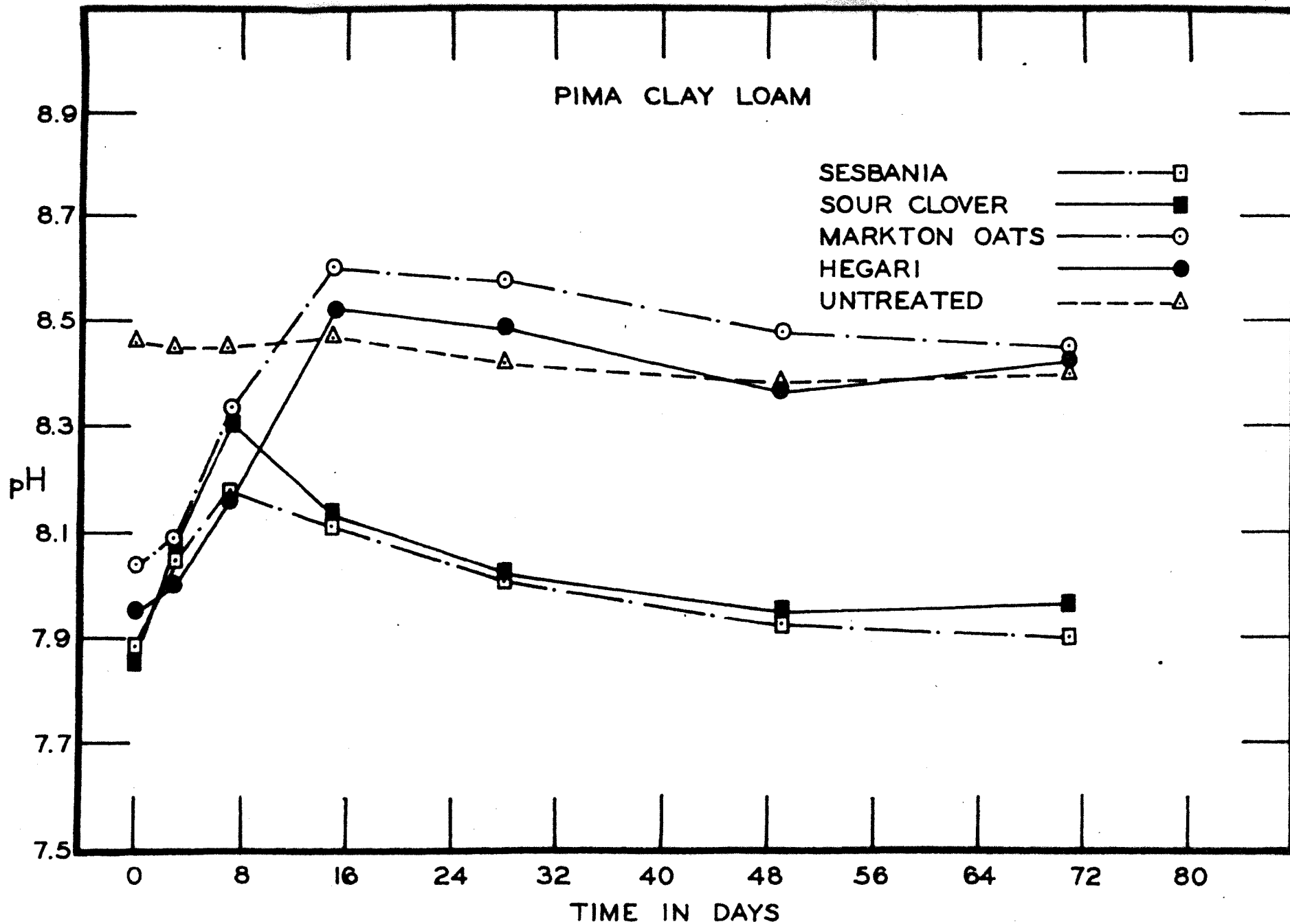


Fig. 3. Reaction changes in samples of Pima clay loam during the decomposition of organic materials.

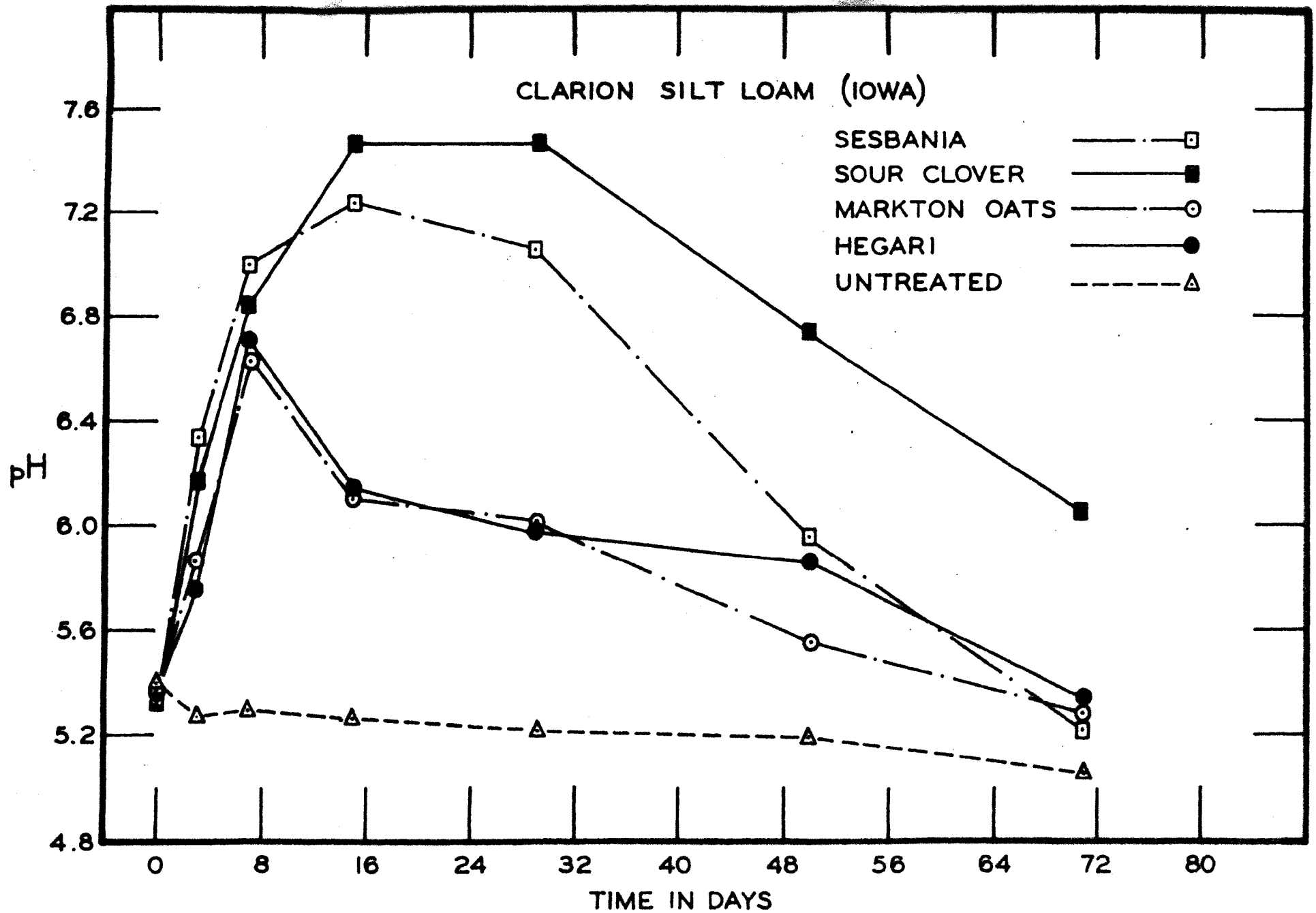


Fig. 4. Reaction changes in samples of Clarion silt loam during the decomposition of organic materials.

sesbania and sour clover caused an average lowering of 0.6 pH unit in the Pima clay loam as compared with 0.4 pH unit for the Markton oats and hegari. Similar differences were observed in the case of the other soils.

Following the initial decrease in reaction, the pH value of all of the organic matter-treated samples rose quickly and in the case of the non-legumes assumed a position slightly above that of the untreated sample. Thereafter, the reaction remained constant or decreased slightly to that of the control samples. It is interesting to note that whereas the non-legume curves levelled off at the end of 15 days' incubation, a similar rate of change was observed in the curves for the percentage of carbon content of the same samples (Figure 1). The legume-treated samples also showed the initial lowering of the pH value, but thereafter the reaction of the soil increased with respect to that of the untreated samples. At the end of an incubation period of seven days, the reaction value again started to decrease. After the 28th day of incubation it remained nearly constant, approximately 0.4 pH unit below that of the check sample in the case of the Pima clay loam and 0.65 pH unit in the case of the Gila sandy loam.

The reaction of the Superstition sand was not affected in the same manner by the organic matter add-

itions except that an initial drop in pH occurred (Figure 5). The reactions of the non-legume-treated samples rose quickly toward that of the untreated soil but never quite reached the same pH and then began to drop slightly, so that after 72 days a difference of only 0.3 pH unit occurred. In addition, the curve reached a maximum and either levelled off or decreased after about 7 days of incubation whereas the Gila and Pima soils required 15 days (Figure 3 and Tables I and II). The Superstition sand was also affected differently by the leguminous plant materials. The reactions of the sesbania and sour clover-treated samples after 15 days of incubation reached the values of 8.89 and 9.03 respectively, which was not only above that of the non-legume-treated samples (pH 8.61 and 8.64), but also above that of the untreated samples (pH 8.77). The curves showed a rapid drop however, particularly in the case of the sesbania-treated samples, and the pH value decreased to a point below both, that of the check sample and those treated with hegari and Markton oats (Table III). It is believed that these reaction changes are intimately associated with the influence of the organic materials on the nitrate content of the samples, a point that will be discussed in a later section.

In contrast with the pH values of the alkaline-calcareous soils when treated with organic materials, the

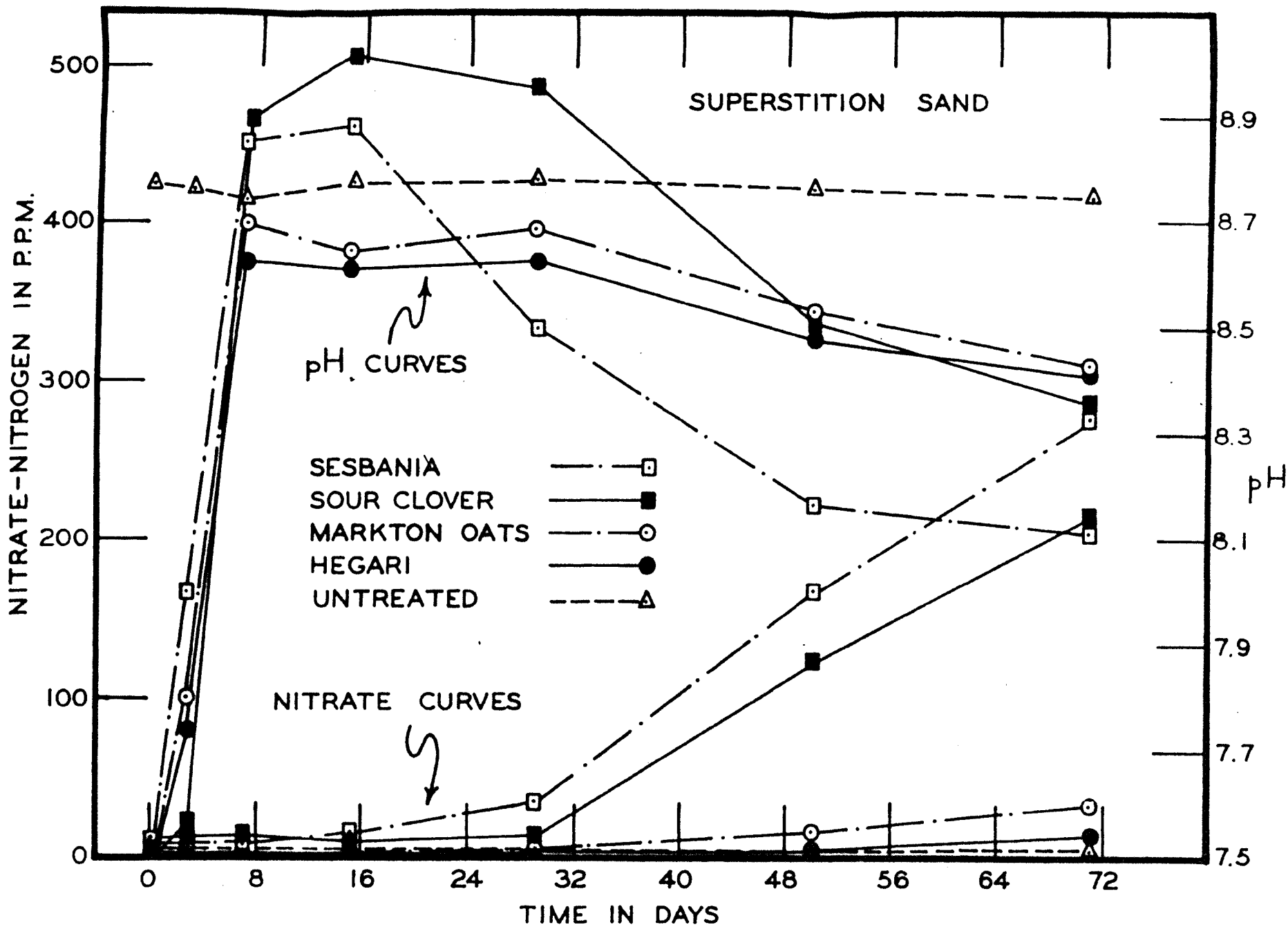


Fig. 5. Changes in the pH and nitrate-nitrogen contents of samples of Superstition sand during the decomposition of organic materials.

acid Clarion soil acted very differently. The initial lowering of the pH upon the addition of the organic substances did not occur. The reaction of the soil was not appreciably affected initially by any of the organic materials. Their decomposition however, affected the pH very markedly. Within three days after the addition of the organic materials the pH had risen about 0.5 pH unit in the case of the hegari- and oat-treated samples and about 0.96 pH unit in the case of the legumes. The non-legumes raised the pH value of the Clarion silt loam from approximately 5.35 to a maximum of 6.70 in 7 days' incubation time after which the pH value dropped gradually until, at the end of the experiment, it reached a value practically identical with that of the untreated sample.

The pH value of the legume-treated samples, on the other hand, rose steadily and reached a maximum value of 7.23 in the case of the sesbania-treated samples and of 7.49 in the case of the sour clover. This represents an average increase of over 2.0 pH units for the legume-treated samples. After reaching a maximum these curves also showed a drop in pH value, with the sesbania-treated samples decreasing more quickly than those treated with sour clover as in the Superstitionsand. After 133 days of incubation the reaction of the sesbania treated samples was approximately 0.34 pH unit lower than that of the

control samples.

These effects of decomposing organic matter are very striking, particularly in view of the observations of Oberholzer (42) that organic matter does not produce an appreciable change in the pH value of alkaline calcareous soils. The pH changes here observed may be related to several fundamental factors: (a) the production of considerable ^{carbon} dioxide during the decomposition; (b) the oxidation of nitrogen to nitric acid; (c) the inherent acidity of the organic matter and the high calcium content of the legumes, present in the form of pectates, proteinate, etc. It is evident, of course, that before any marked decrease in pH value can occur, the buffer capacity of the soil must be overcome. Probably the most effective of the above enumerated factors is the oxidation of the nitrogen to nitric acid. The effect of this factor will be presented in a later section at which time these reaction changes will be further elaborated.

Accumulation of Nitrates

The influence of the decomposition of organic materials on the nitrate-nitrogen contents of the different soils is indicated by the data in column 5 of Tables I-IV, and is depicted in Figures 5, 6, and 7. It is evident that in the presence of the leguminous plant materials the nitrate nitrogen originally present in each soil was absorbed by the microorganisms, but in the case of the Pima clay loam nitrates were soon released (within 7 to 10 days) and accumulated rapidly so that within 28 days over 300 p.p.m. had accumulated in each case. Thereafter nitrification was less rapid so that during the next 105 days only about 200 p.p.m. of nitrate-nitrogen had accumulated.

It is interesting to note in regard to the Pima soil that, although practically equivalent quantities of nitrogen were added to this soil by way of sesbania and sour clover, the nitrogen was released and oxidized to nitrates more quickly in the case of the sour clover than in the case of the sesbania. Since the speed of decomposition of the sour clover was greater than that of the sesbania, such a change was to be expected. The data in column 5 of Table I show that the changes in the Gila sandy loam soil were almost identical with those

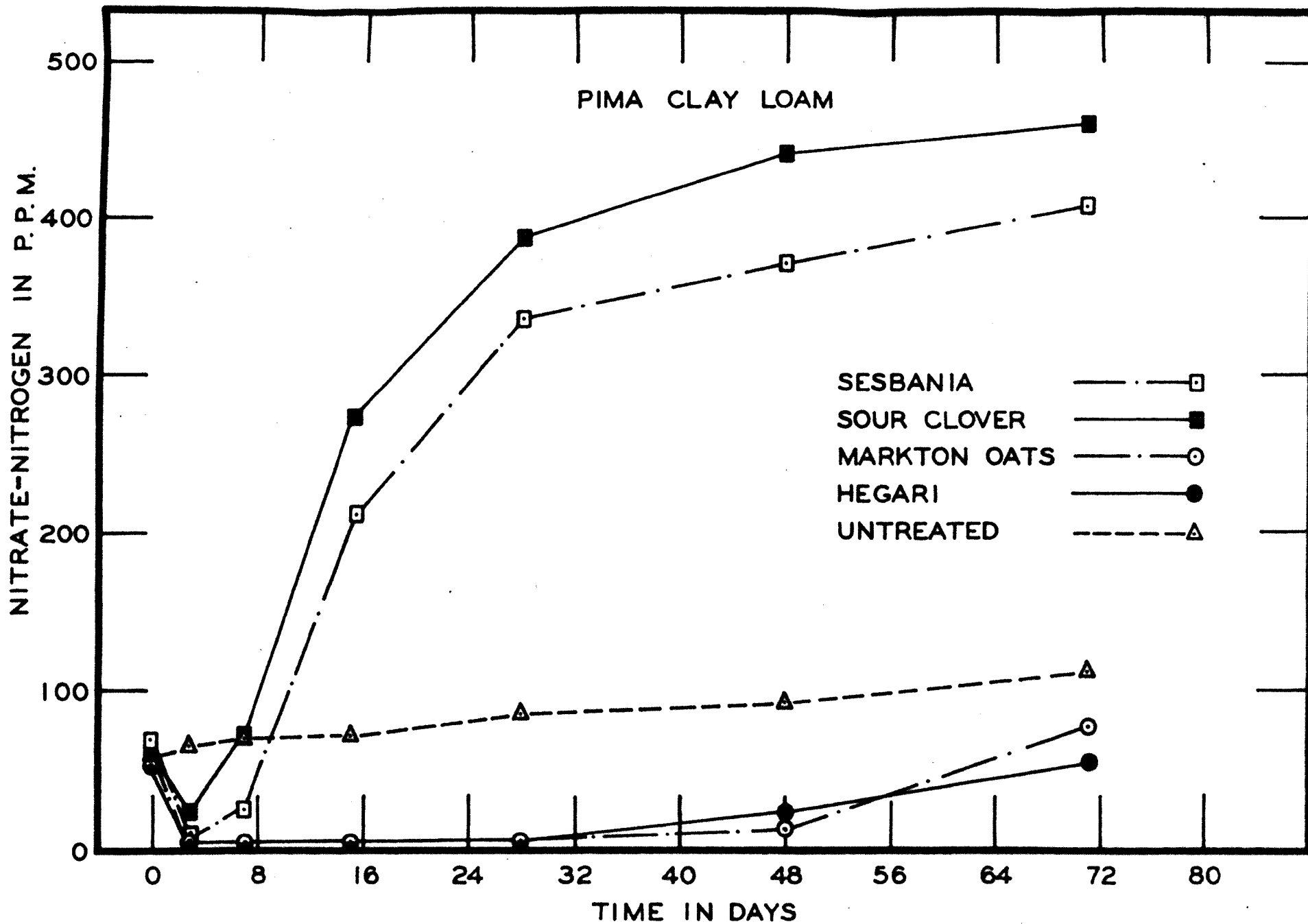


Fig. 6. Changes in the nitrate-nitrogen contents of samples of Pima clay loam during the decomposition of organic materials.

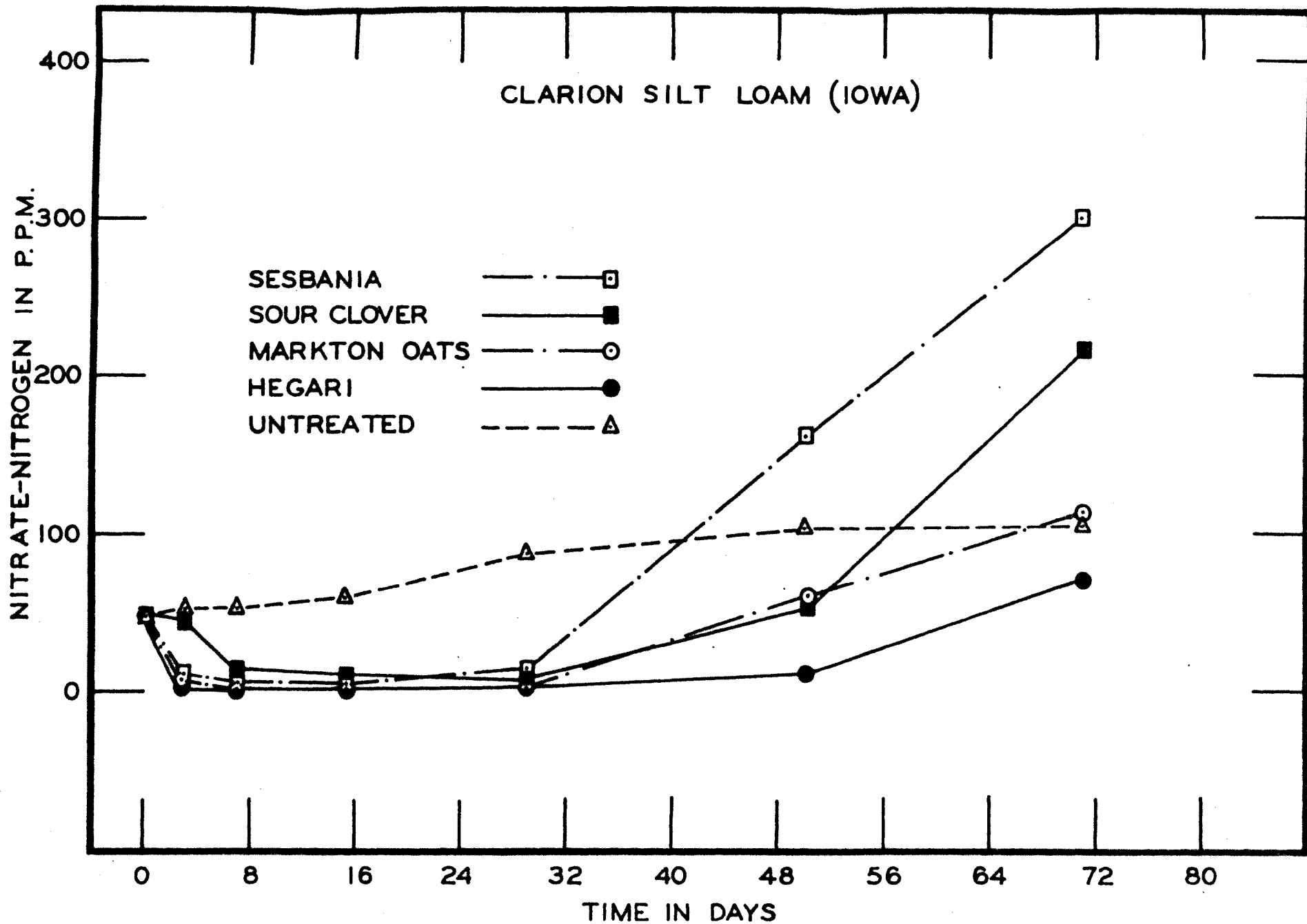


Fig. 7. Changes in the nitrate-nitrogen contents of samples of Clarion silt loam during the decomposition of organic materials.

of the Pima clay loam in this respect.

The results with the Superstition sand and Clarion silt loam, insofar as the leguminous plant materials were concerned, differed markedly from those of the Pima and Gila soils. In the Clarion silt loam (Table IV) the nitrates already present in the soil were promptly absorbed by the microorganisms in the presence of both the sesbania and the sour clover and nitrates did not accumulate for a period of 28 days rather than the period of 7 to 10 days which was the case in the other two soils. Nitrates then began to accumulate in the legume-treated samples, but it was not until after 40 days of incubation had elapsed in the case of the sesbania and some 56 days in the case of the sour clover that the nitrates accumulated in amounts equal to those in the untreated samples.

Whereas only a trace of nitrate-nitrogen was present in the untreated samples of Superstition sand so that the leguminous plant materials could not utilize the nitrogen of the soil, release of nitrogen as nitrates from the legume-treated samples did not begin to occur in appreciable quantities until after about 28 days of incubation and thereafter its rate of accumulation, although steady, was not very rapid. It is interesting to note that the rate of accumulation of nitrate-nitrogen from the two legume-treated samples of both the very alkaline Super-

stition sand and the acid Clarion silt loam was almost the same, the two curves being practically superimposable.

It should also be pointed out that whereas the nitrogen in sour clover was released most quickly as nitrates in both the Pima clay loam and Gila sandy loam (Tables I and II), the nitrogen in sesbania rather than in the sour clover was released the most quickly in both the Superstition sand and Clarion silt loam (Tables III and IV.)

It is interesting to note, (Table IV,) that, although the decomposition of the plant materials was more rapid in the Clarion silt loam than in any of the other soils tested (See Table V) and the sour clover decomposed in this soil more rapidly than did the sesbania, nitrates accumulated less rapidly; also the accumulation was less rapid from the sour clover than from the sesbania.

The non-leguminous materials affected the nitrates in a similar manner in all of the soils. Nitrates were absorbed by the microorganisms immediately, and nitrate accumulation did not occur until after about 28 days of incubation. At the end of this time slight increases in the nitrate-nitrogen content of the non-legume-treated samples began to occur so that at the end of 70 days of incubation nearly as much, or slightly more, nitrate-nitrogen had accumulated as was present at that time in the check samples. In each instance, nitrates were released

slightly more rapidly from the Markton oats-treated samples than from those treated with hegari.

Changes in Total Soluble Salts

From the appropriate columns in Tables I-IV and on the basis of Figures 8 and 9 it is evident that all of the organic materials initially caused an increase in the water soluble salt contents of all of the samples. Since the water-soluble fraction of each of the organic materials was appreciable, (Table VI), such a result was to be anticipated. Correlating with the initially rapid decomposition of the water-soluble fraction of the organic materials, a rapid decrease in the total soluble salt contents of the samples occurred. In the case of the non-leguminous substances the amount of total soluble salts was equivalent to or slightly less than the amount present in the untreated soil, but on further incubation (at the end of either 72 or 133 days) the treated samples showed a greater salt content than that of the check samples. In the case of the Gila and Superstition soils, (Tables I and III), the salt contents of the non-legume-treated samples were always higher than those of the control samples but the shape of the curves was similar to those of the Clarion and Pima soils. It should also be noted that the hegari-treated samples always showed a slightly higher salt content than those treated with Markton oats though the two curves were roughly parallel for each soil

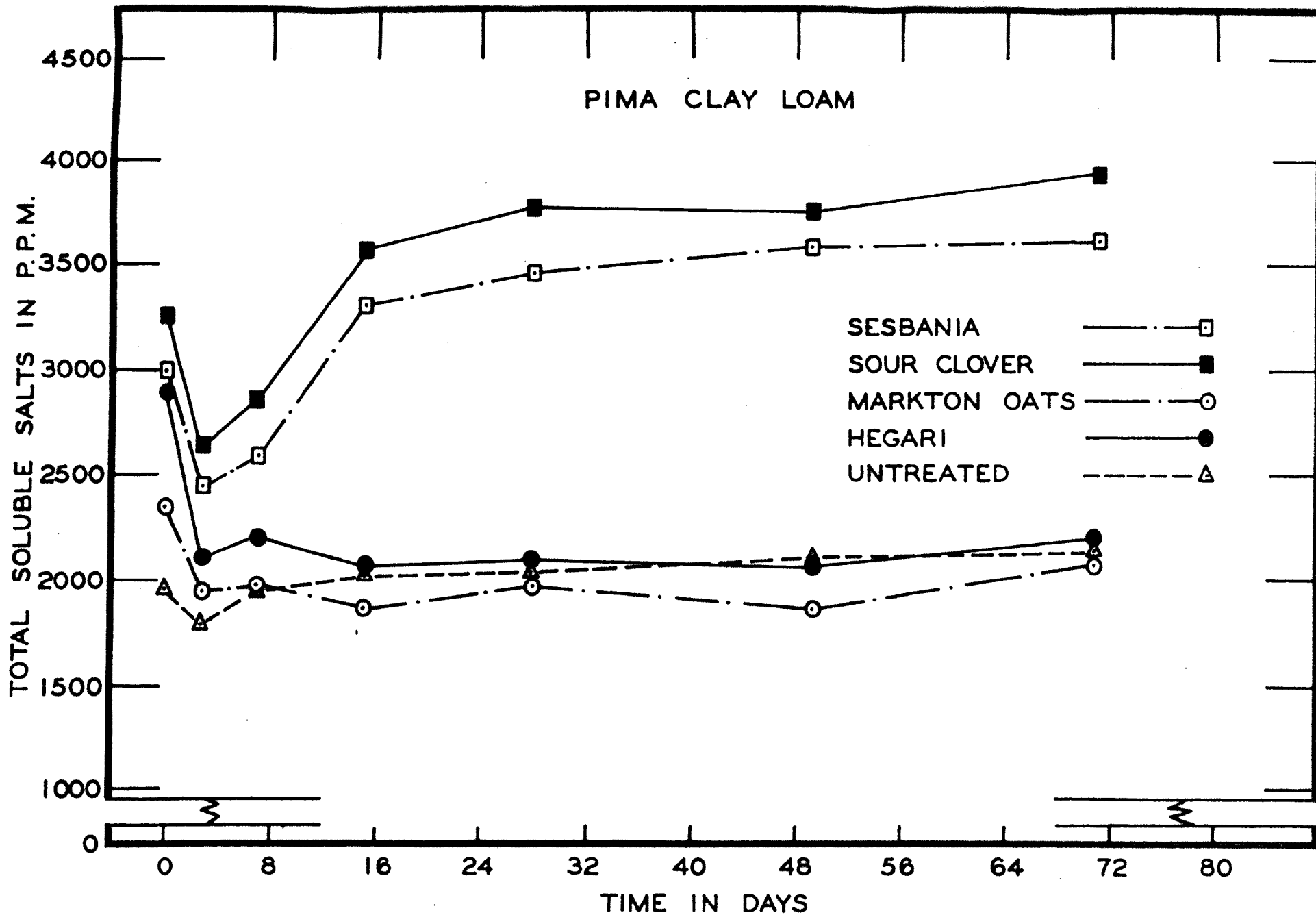


Fig. 8. Changes in total soluble salt contents of samples of Pima clay loam during the decomposition of organic materials.

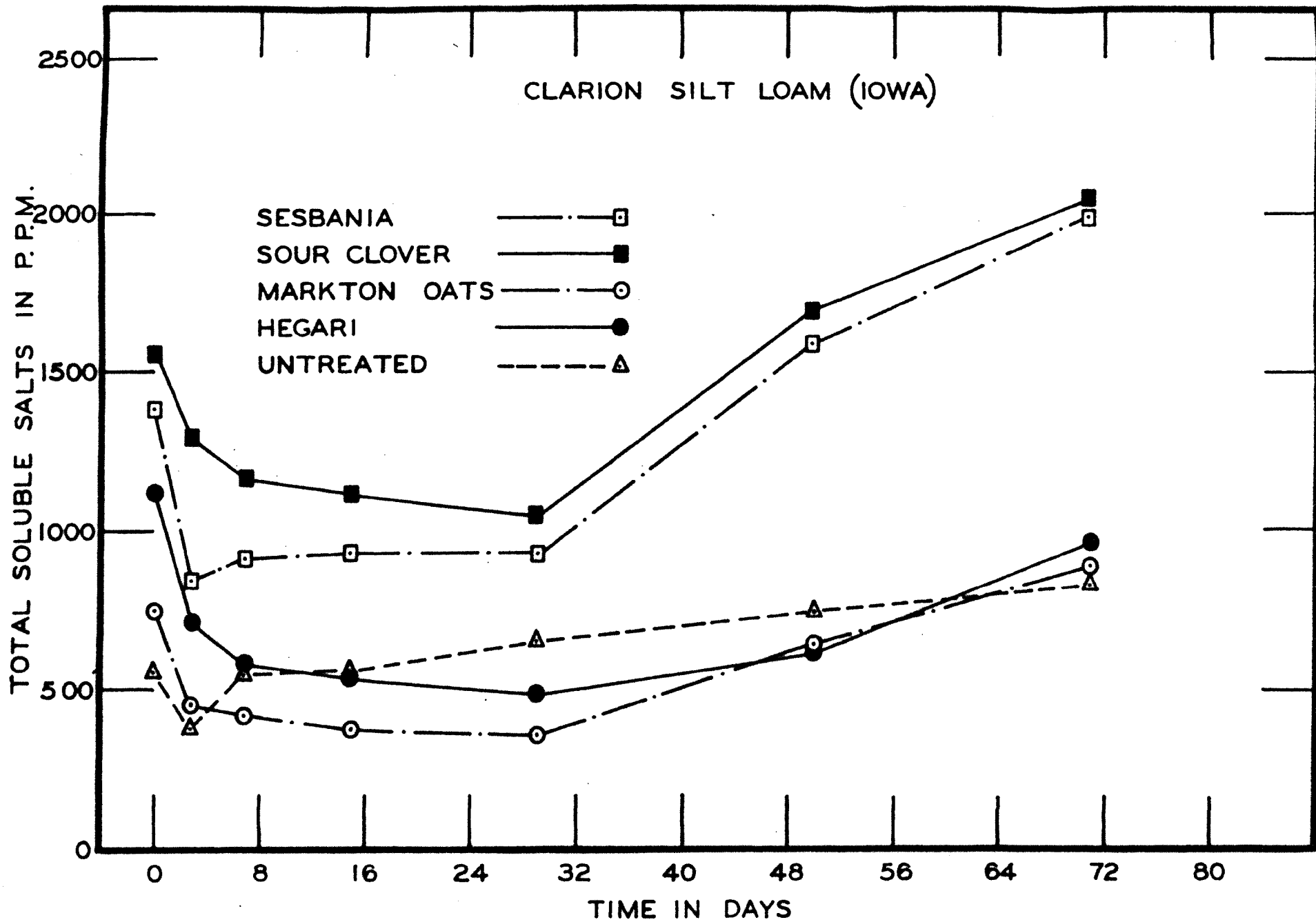


Fig. 9. Changes in total soluble salt contents of samples of Clarion silt loam during the decomposition of organic materials.

tested.

Initially in all soils the legume-treated samples had a higher content of total soluble salts than those treated with the non-legumes, and the salt content decreased quickly during the first few days of incubation much as in the case of the non-legume-treated samples. The decrease was not, however, as great as in the samples treated with hegari and Markton oats, and the curves began to rise after a few days indicating that as decomposition proceeded large increases in the total soluble salt contents occurred. The initial decrease in salt content of the legume-treated samples was arrested sooner in the Pima clay loam so that the salts began to accumulate more rapidly than in the case of the Clarion silt loam. Decreases in the salt content began to occur in three days of incubation in the Pima clay loam soil whereas about 28 days of incubation were required in the case of the Clarion silt loam. In all instances the sour-clover-treated samples showed a higher total soluble salt content than the samples treated with sesbania.

Changes in Aggregation of Soil Particles

Since it has been shown by Mc George (37) and others that soil structure is of great importance in soil fertility; and, since it is generally recognized that organic matter is an important factor in determining soil structure, it was decided that some determination of the effect

of decomposing organic materials on the structural relationships of the soil should be made. Consequently, since soil aggregates are a measure of soil structure, it was decided that the determination of the water stable aggregates according to the method of Gerdel (26), (previously explained in the section on methods of analysis), would serve this purpose.

The results of these analyses are shown in the last column of Tables I-IV and in Figures 10 and 11. In all cases the addition of organic materials was found to decrease the percentage of soil particles less than 0.05 mm. in diameter, indicating the formation of aggregates or "soil crumbs" of a diameter larger than that mentioned above. In all soils the extent of aggregation increased steadily during the entire course of the incubation period, with the most rapid aggregation formation occurring during the first 7 to 15 days of incubation. At the end of 133 days an average decrease of about 15 percent in particles less than 0.05 mm. in size occurred in the case of the Pima clay loam soil and of about 19 percent in the Clarion silt loam.

The non-legumes caused a greater aggregation of the soil particles than the legumes in each soil tested. Markton oats caused a greater degree of aggregation than the hegari; and, of the leguminous plants, the sesbania

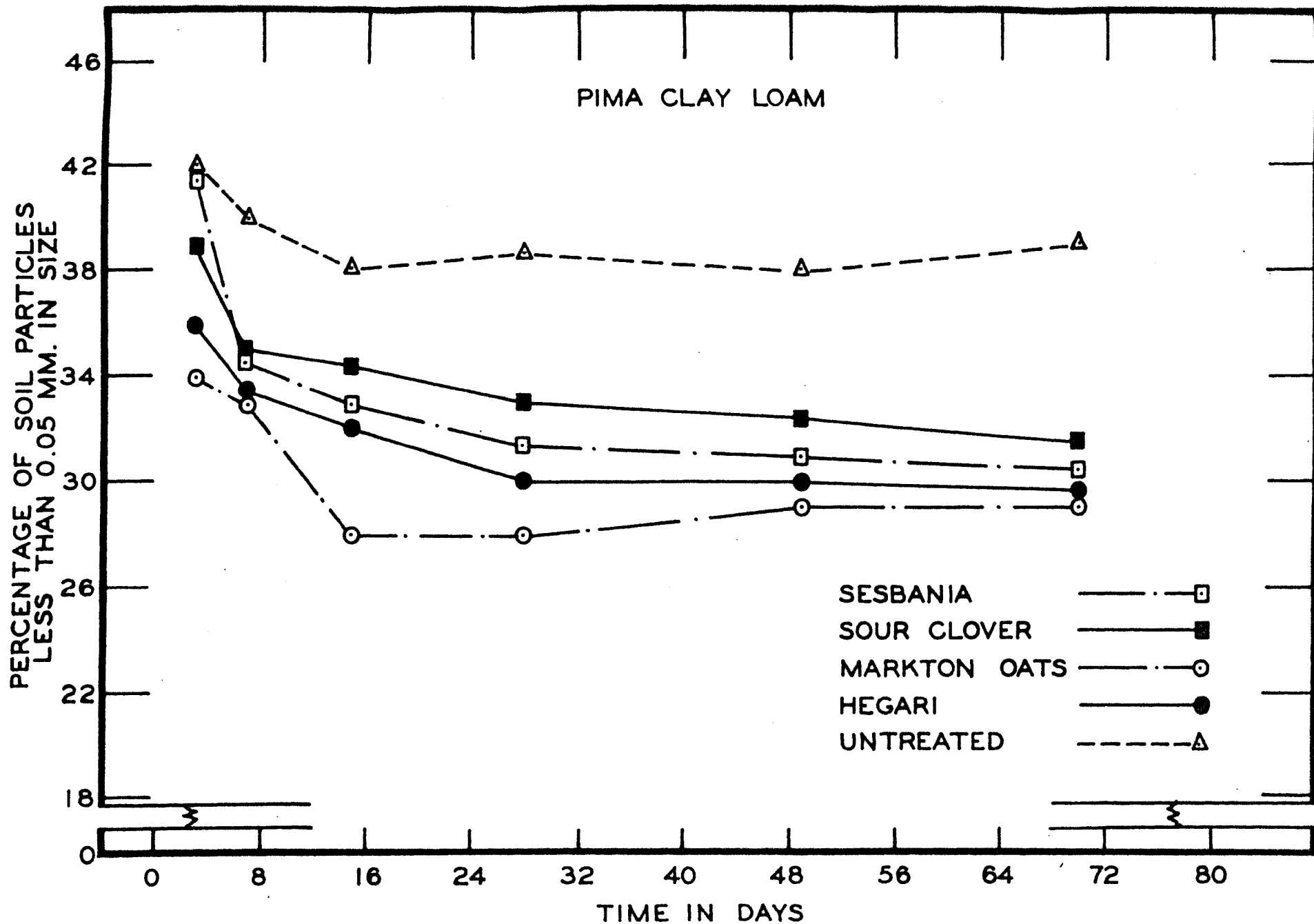


Fig. 10. Effect of the decomposition of organic materials on particle size in samples of Pima clay loam.

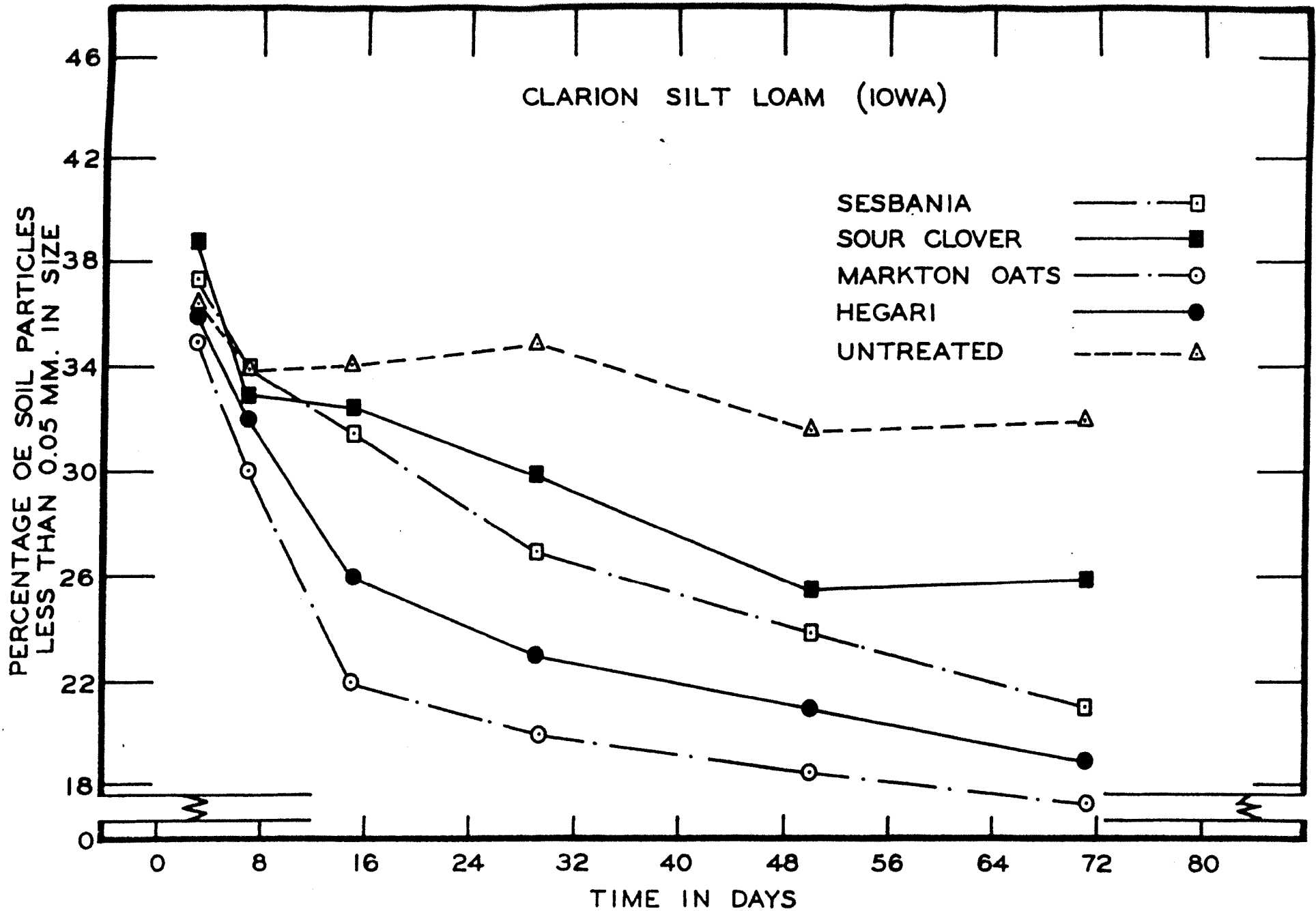


Fig. 11. Effect of the decomposition of organic materials on particle size in samples of Clarion silt loam.

was more effective in this regard than the sour clover.

It should be noted that even though the Clarion silt loam contained considerably more organic matter than the Pima clay loam (Table VI) and even though it was a silt loam whereas the Pima soil was a clay loam, the organic matter additions caused a greater aggregation of the small particles of the Clarion silt loam than of the Pima clay loam. In addition, the difference between any two organic substances was greater in the Clarion than in the Pima soil. For example, at the end of 70 days of incubation, the difference between the percentage of particles less than 0.05 mm. in the sesbania-treated samples as compared with those treated with Markton oats was 5 percent in the Clarion silt loam and only 1 percent in the Pima clay loam.

DISCUSSION OF RESULTS

The results presented in the preceding sections may now be summarized and discussed. In view of the fact that these phenomena are so closely interrelated, it is desirable to correlate the data in order to arrive at a coordinated picture of the mechanism.

Reference to the total carbon determinations given in Tables I to IV shows that in every soil the addition of each of the various organic materials brought about a typical change: that is, a very rapid initial decomposition, followed by a gradual decrease in the rate of decomposition.

The rate of decomposition was found to vary with the organic material and with the soil used. Table VI gives the chemical analyses of the various organic materials, and shows that the different green manures used in the experiment varied quite widely in chemical composition.

Since the carbon content (Table VI) was approximately the same in the different materials, and the nitrogen content was about twice as high in the legumes as in the non-legumes, the legumes obviously had a much lower carbon-nitrogen ratio than the non-legumes.

The lower carbon-nitrogen ratio in the legumes resulted in a more rapid initial decomposition for the

legumes than the non-legumes in the alkaline calcareous soils. This was the result anticipated, since it has been shown by many investigators, including Martin (32), Scott (54), Waksman and Tenney (66), and others, that the higher the carbon-nitrogen ratio the slower the decomposition of the organic material in the soil.

Strangely, however, in the Clarion silt loam, an acid soil, the large difference in the carbon-nitrogen ratio did not seem to affect the rate of decomposition to any great extent, as may be seen from Table V. The reason for this unusual phenomenon is not readily apparent. One explanation which has been proposed is that the early rapid decomposition in this soil may have occurred sooner than in the alkaline-calcareous soils. This effect might have been caused by a larger total microbial population present in the soil as a result of its naturally larger humus content. Probably the most logical explanation is that the Clarion silt loam, because of its large humus content, contained enough nitrogen initially to reduce the high carbon-nitrogen ratio of the various plant materials sufficiently that the ratio in the soil became so low in all cases as not to affect the rate of decomposition. The high initial nitrate-nitrogen content of 60 p.p.m. in this soil would indicate that such was actually the case.

Over a long period of time it was found (Table V) that in all of the soils used a greater percentage of added carbon was lost in the non-legume-treated samples and the sour clover-treated samples than in those treated with sesbania. An explanation for this phenomenon may be found in a consideration of the chemical composition of the different organic materials used (Table VI). Since the non-legumes contain a smaller percentage of nitrogen than the legumes, less protoplasm can be synthesized at any one time by the microorganisms bringing about the decomposition; consequently, over a long period of time one would expect a larger carbon loss from the added non-leguminous plants than from the legumes.

In the case of the sour clover, however, the large carbon loss is due to an entirely different reason. The sour clover contains twice as large a percentage of cold-water-soluble material as the sesbania (Table VI). Naturally then, since Oberholzer (42), Waksman and Tenney (66), and others have shown that the water-soluble fraction of organic materials decomposes most rapidly, one would expect a larger carbon loss in the case of the sour clover than in the case of the sesbania during the same period of time. Such a loss was actually found to occur in each of the soils studied.

The reaction of the soil seems to have con-

TABLE VI. CHEMICAL COMPOSITION OF PLANT MATERIALS.

	Ses- bania	Sour Clover	Hegari	Markton oats
Total carbon (%)....	53.44	50.43	51.93	54.96
Total nitrogen (1%).	3.38	3.61	1.39	1.35
C/N ratio.....	15.81	13.97	37.36	40.71
Moisture (%).....	6.21	5.59	4.80	5.74
Cold water soluble fraction (%).....	22.69	42.52	14.98	9.94
Hot water soluble fraction (%).....	2.72	2.14	2.95	3.48
Alcohol soluble fraction (%).....	4.15	2.16	1.84	1.53
Ether soluble fraction (%).....	3.12	2.93	2.39	4.38
Ash constituents (%)	7.90	13.53	9.68	10.80
Calcium (%).....	0.91	1.26	0.28	0.12
P ₂ O ₅ (%).....	0.57	0.47	0.35	0.69

siderable influence upon the rate of decomposition. The rate of decomposition of all the organic materials in the Clarion silt loam was considerably more rapid throughout the entire course of the experiment than the decomposition rate in any of the alkaline calcareous soils.

This is in agreement with the conclusions of Stephenson (58), who also found that the decomposition of organic materials was more rapid in acid soils than in alkaline soils. However, Oberholzer, (42) comparing the results he obtained in alkaline soils with those obtained by Waksman and Tenney (66) in acid soils, came to the conclusion that organic matter disappears more rapidly from the soils of arid-irrigated regions than from those of humid regions. Such is probably the case under normal agricultural conditions in the two regions because of the higher temperatures prevailing in arid soils, but the present finding throws some doubt on the truth of Oberholzer's conclusion when identical experimental conditions are used.

If, as is commonly believed, the molds are more numerous in acid soils than in alkaline soils - because of less competition from the bacteria and actinomyces for the available food supplies - and if, as is generally accepted, the molds are more active organic-matter decomposers than the other microorganisms, then the greater speed of decomposition at a given temperature in the acid soils may be due to the greater proportion of molds to bacteria and actinomyces in such soils.

Contrary to the findings of Oberholzer (42), Sackett, Ferguson, and Ward (51), and others, who concluded that decomposing organic materials have no significant effect upon the reaction of soils, it was found in the present investigation that the addition of organic materials to the soil has a marked effect on the pH value, not only initially, but also during the entire course of the decomposition. This conclusion is also substantiated by the investigations of Conrad (20), Dyal, et al. (23), and Humfeld and Smith (29).

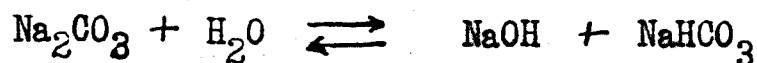
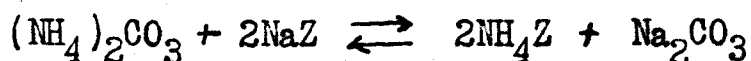
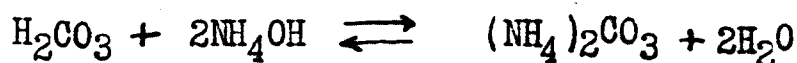
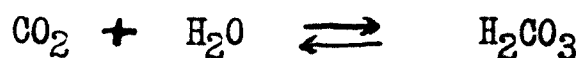
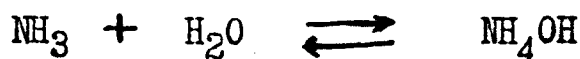
All of the organic materials caused an initial drop in the pH of the alkaline calcareous soils. A suspension of 2 grams of the non-leguminous plant materials in 500 ml. of distilled water showed an average pH of 6.5; the corresponding value for the legumes was 6.23. The addition of 2 grams of these materials to the soil and the suspension of the whole in 500 ml. of distilled water probably would result in a pH value somewhere between that of the original soil and that of the organic material. This statement would not hold true in every case, however, since there could possibly be an interaction between the organic matter and the soil that would result in a repression of the acids or bases of one or the other. In this investigation in the alkaline soils the above lowering did occur, however, with the decrease in pH value depending to a considerable extent upon the buffer capacity of

the particular soil.

Rapid decomposition of the water-soluble fraction of the organic materials, provided that by-products of the decomposition are not formed which influence the reaction of the soil, would probably cause the pH value to change toward that of the original soil, and such was found to be the case in the alkaline soils used in this investigation. However, it is quite certain that the formation of certain products of the decomposition process, particularly ammonia, very probably aided in the causing the observed increase in the reaction value in these soils during this decomposition process.

In the Clarion silt loam, however, the addition of the organic materials did not affect the pH value of the soil. Since the original soil had a pH value of 5.4 and the organic matter suspensions a pH value of 6.23 to 6.5, it was expected that the addition of the organic materials would cause the system to become somewhat more alkaline. Although such was not the case, during the first 7 days of decomposition, the reactions of all the organic matter-treated samples increased from 1.23 to 1.66 pH units, after which the reaction of the non-legume-treated samples gradually decreased toward that of the untreated soil, and the reaction of the legume-treated samples continued to rise to a maximum pH value of 7.23 in the case of the sesbania and 7.49 for the sour clover.

It is believed that an explanation of these phenomena can be found in a consideration of the following well-established facts. Large amounts of nitrogen are present, having been added to the soils by way of leguminous plant materials. Although this nitrogen is present in a complex nitrogenous or proteinaceous form, it is quickly released as ammonia, which is fixed by base exchange, and the hydrolysis of the sodium carbonate formed imparts an alkaline reaction to the soil. This may be represented by the following equations:



Since the sodium hydroxide thus formed is completely ionized, causing a large addition of hydroxyl ions to the solution, obviously the soil solution becomes alkaline to a degree depending on the amount of ammonia formed.

Ammonification is brought about by most of the microorganisms of the soil - most soil microbes being heterotrophs - and the process is known to be rapid in both acid and alkaline soils. The ammonia that is formed

is capable of being oxidized by the nitrifying bacteria to nitrous and nitric acids which impart an acid reaction to the soil in direct contrast to the alkalizing effect of the ammonia. Whether or not the legume-treated soils become highly alkaline or acid depends, then, upon the speed of nitrification or the speed with which the ammonia is utilized.

The optimum pH value for the growth and activity of the nitritifiers is approximately 7.8, and of the nitrifiers 7.1 (67), so oxidation of the ammonia to nitrates and nitrites should be most rapid in alkaline and least rapid in acid soils. That such was actually the case in this investigation is shown in Figures 6 and 7. The high pH of the legume-treated Clarion silt loam prior to nitrate formation, may therefore, have been due to the accumulation of ammonia.

The fact that the legume-treated samples of Pima clay loam never became as basic as, or more basic than, the untreated samples probably rests with the extremely rapid rate at which nitrates accumulated and rendered the soil less alkaline. The relationship of nitrate accumulation and pH is quite evident from Figures 12 and 13 in which both variables have been plotted on the same graph. This is emphasized even more strikingly in Figure 5 in which the changes in the pH and

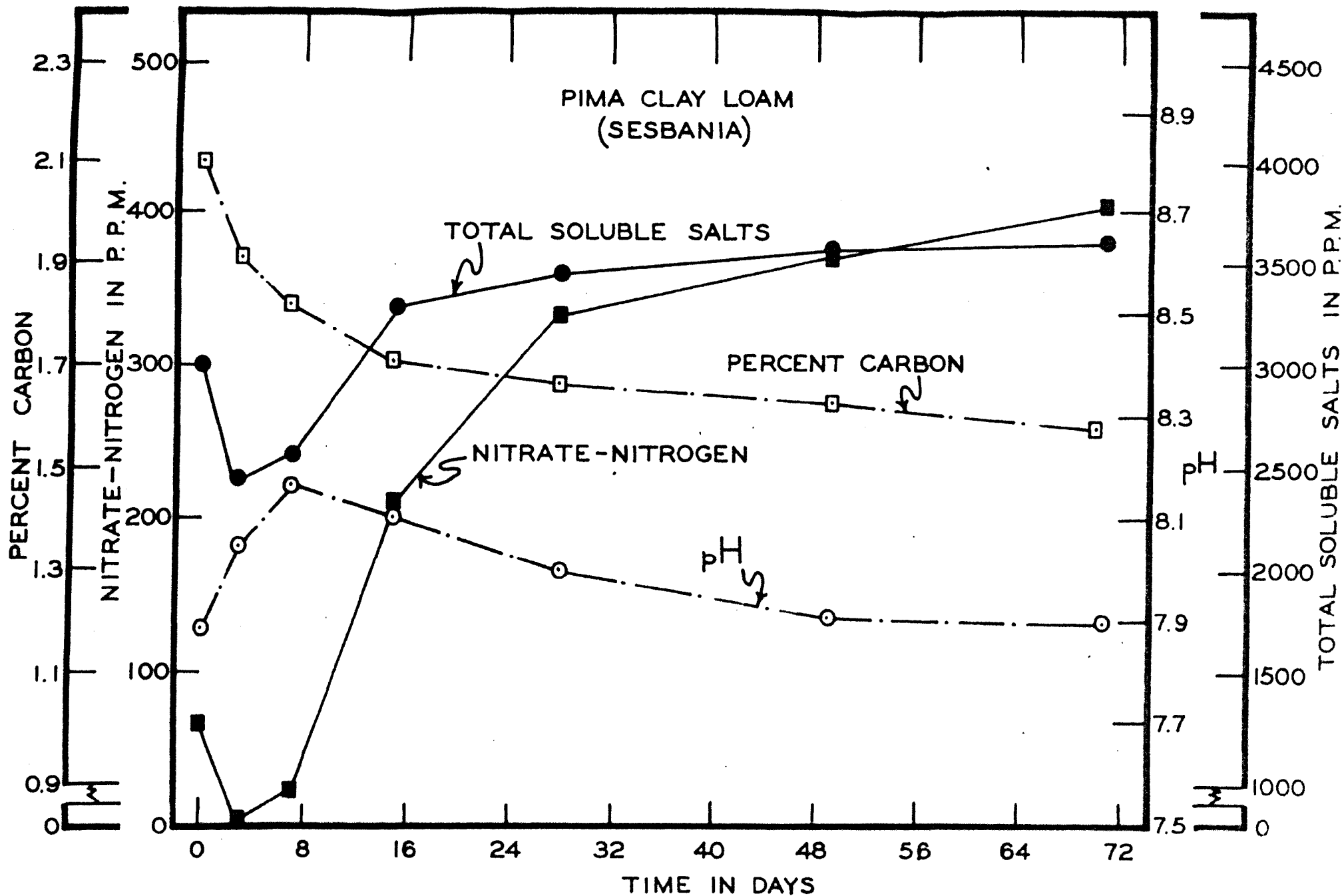


Fig. 12. Effect of the decomposition of sesbania on the percent carbon, pH, nitrate-nitrogen and total soluble salt contents of samples of Pima clay loam.

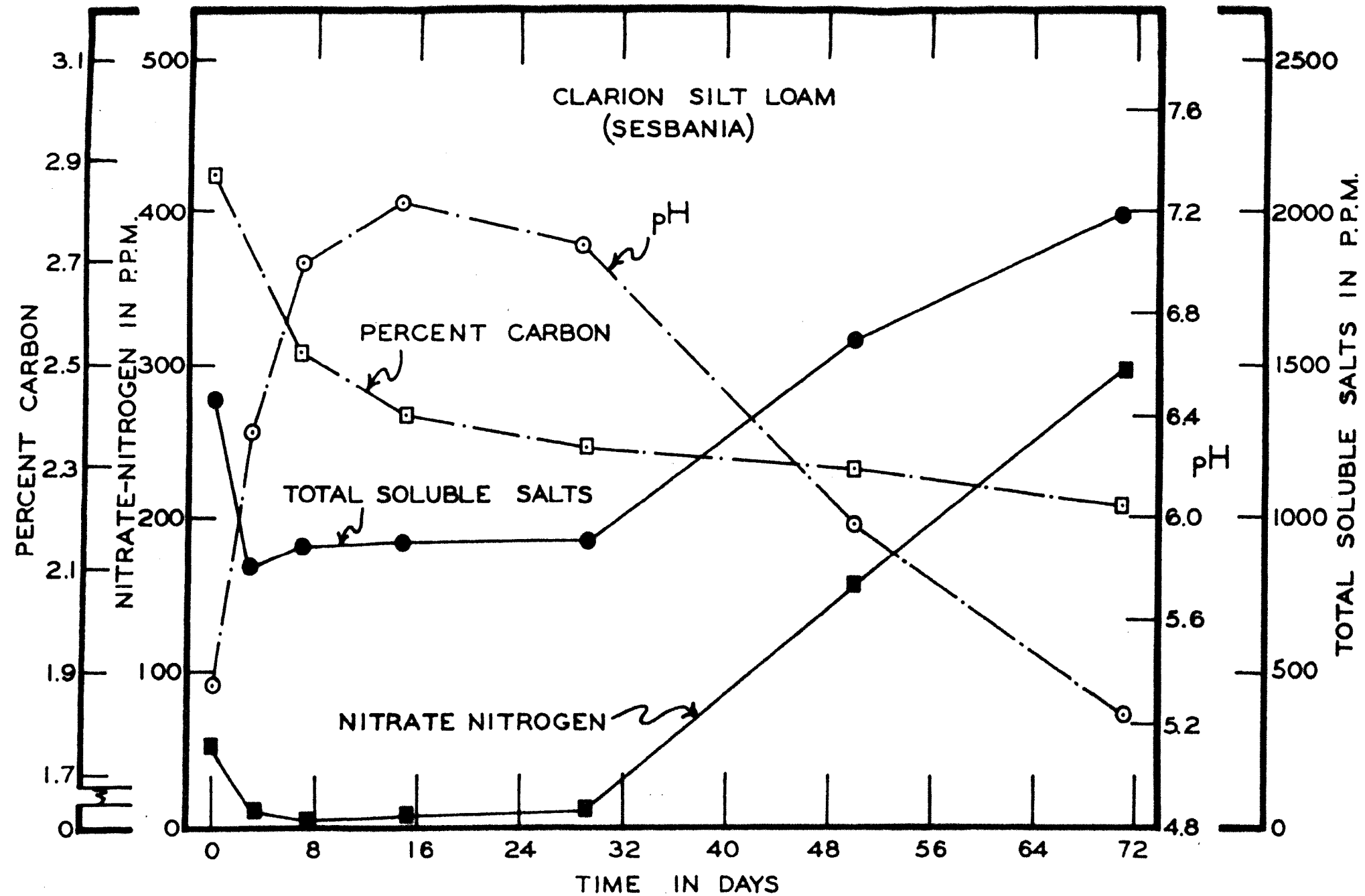


Fig. 13. Effect of the decomposition of sesbania on the percent carbon, pH, nitrate-nitrogen and total soluble salt contents of samples of Clarion silt loam.

nitrate-nitrogen contents of the samples of Superstition sand have been plotted on the same graph (figure 5).

The above explanation is therefore probably the correct one, rather than some unaccounted for difference between the acid and alkaline soils.

The Superstition sand is also an alkaline-calcareous soil with a pH of 8.77; yet in this soil, because of certain unknown deficiencies of the nitrifying bacteria or possibly because of very small numbers present, nitrates do not begin to accumulate until after 15 days of incubation and not to a very large extent until after 28 days of incubation. There is, therefore, plenty of time for ammonia to accumulate and impart a reaction to the soil, making it more basic than that of the untreated samples, as in the case of the acid Clarion silt loam Figure (4). When nitrates begin to accumulate in the Superstition sand, however, the pH value immediately becomes less and the decrease is most rapid when legumes are present as in the case of the sesbania-treated samples, which are also the ones in which nitrates are formed most rapidly.

In all of the soils the addition of the various plant materials caused the soluble nitrate-nitrogen content to be very quickly absorbed as part of the microbial protoplasm. However, in every soil used in the ex-

periment the nitrogen was released as nitrates more quickly in the legume-treated than in the non-legume-treated samples, showing, as many other investigators have found, (6,32,41,57), that the carbon-nitrogen ratio of the added organic material controls the rate of nitrification to a very large degree. However, it is evident that the rate of nitrification is also influenced by other factors, as is shown by the fact that the production of nitrates was always much more rapid in the Gila sandy loam and the Pima clay loam than in either the Superstition sand or the Clarion silt loam. For example, in the case of the sour clover-treated samples it was found that 67.6% and 61.8% of the organic nitrogen added to the Gila sandy loam and the Pima clay loam respectively, was converted to nitrates by the end of 133 days, whereas only 36.6% and 38.7% of the organic nitrogen added to the Superstition sand and the Clarion silt loam respectively, was so converted in the same period of time.

The total salt content of the soil solution increased with the addition of the organic materials (Tables I-IV and Figures 8 and 9). This observation is in agreement with that of Oberholzer (42), who found that within 12 hours after the addition of organic matter, the calcium content of the soil solution was increased by alfalfa about 800 p.p.m. and by hegari about 600 p.p.m.

with corresponding increases in the bicarbonate content.

The initial increase in total soluble salts observed in the present investigation was apparently due to the appreciable amount of water-stable substances present in the organic materials. It will be noted that in every soil the sour clover always caused the largest initial increase in the salt content, which should be expected from the large water-soluble fraction shown in Table VI. It is also significant that the order of percentages of water-soluble material as given in Table VI is always the same as the order of the initial increases in the total soluble salt content.

In this investigation, in all cases the legumes caused a greater increase in the total soluble salt content of the soil solution than did the non-legumes. (Tables I-IV) which obviously should be expected from the chemical analyses given in Table VI. The decomposition during the first three days caused a decrease in the total soluble salt content as is shown in Figures 8 and 9.

After this decrease, the non-legumes had little effect on the total soluble salts during the decomposition process until toward the end of the incubation period when the nitrates began to accumulate. The soils in which legumes had been incorporated, however, soon after the initial drop, showed a marked increase in the

total soluble salt content. In all cases, (Figures 12, 13, 14, and 15, this increase correlated very closely with the production of nitrates, indicating a very definite relationship between the two quantities.

In this connection it is very interesting to note that the increase in total soluble salts can almost quantitatively be accounted for by the nitrates formed. For example, in the Pima soil, the difference in the total soluble salt content of the untreated sample and the sour clover-treated sample was 2000 p.p.m. During this period of time 450 p.p.m. of nitrate-nitrogen accumulated and this is equivalent to 1925 p.p.m. of nitric acid. Although it is realized that all the nitrates are probably not present as nitric acid, and that, therefore, the above calculations are somewhat fortuitous, nevertheless, this does seem to indicate relatively that small amounts of water-soluble material other than nitrates are being formed during the later stages of decomposition.

Several reactions may be considered responsible for the decrease in soluble salt content of the soils that resulted from the decomposition of the organic matter during the first few days (Tables I-IV) and Figures 8 and 9). Among these may probably be included the following:

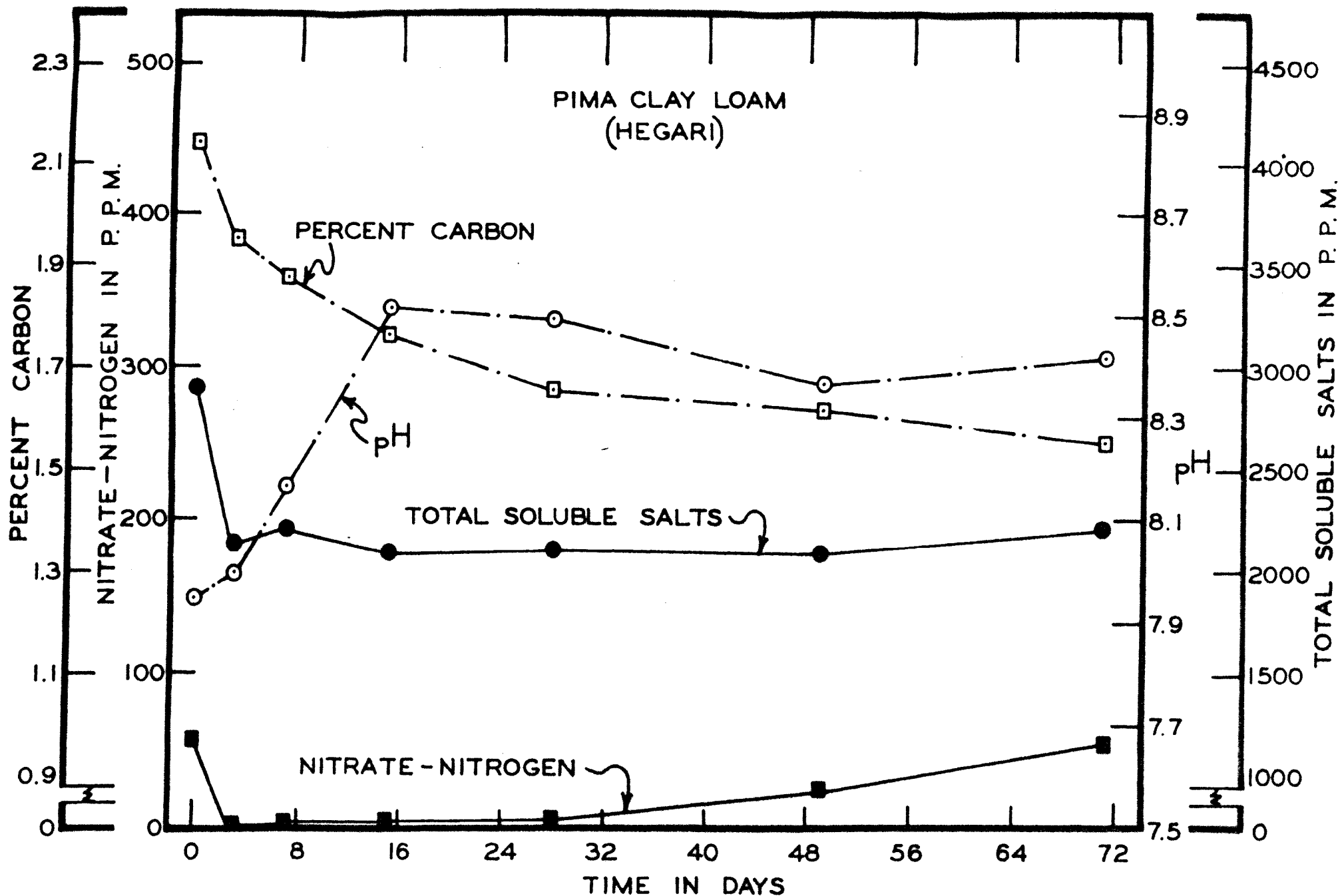


Fig. 14. Effect of the decomposition of hegari on the percent carbon, pH, nitrate-nitrogen and total soluble salt contents of samples of Pima clay loam.

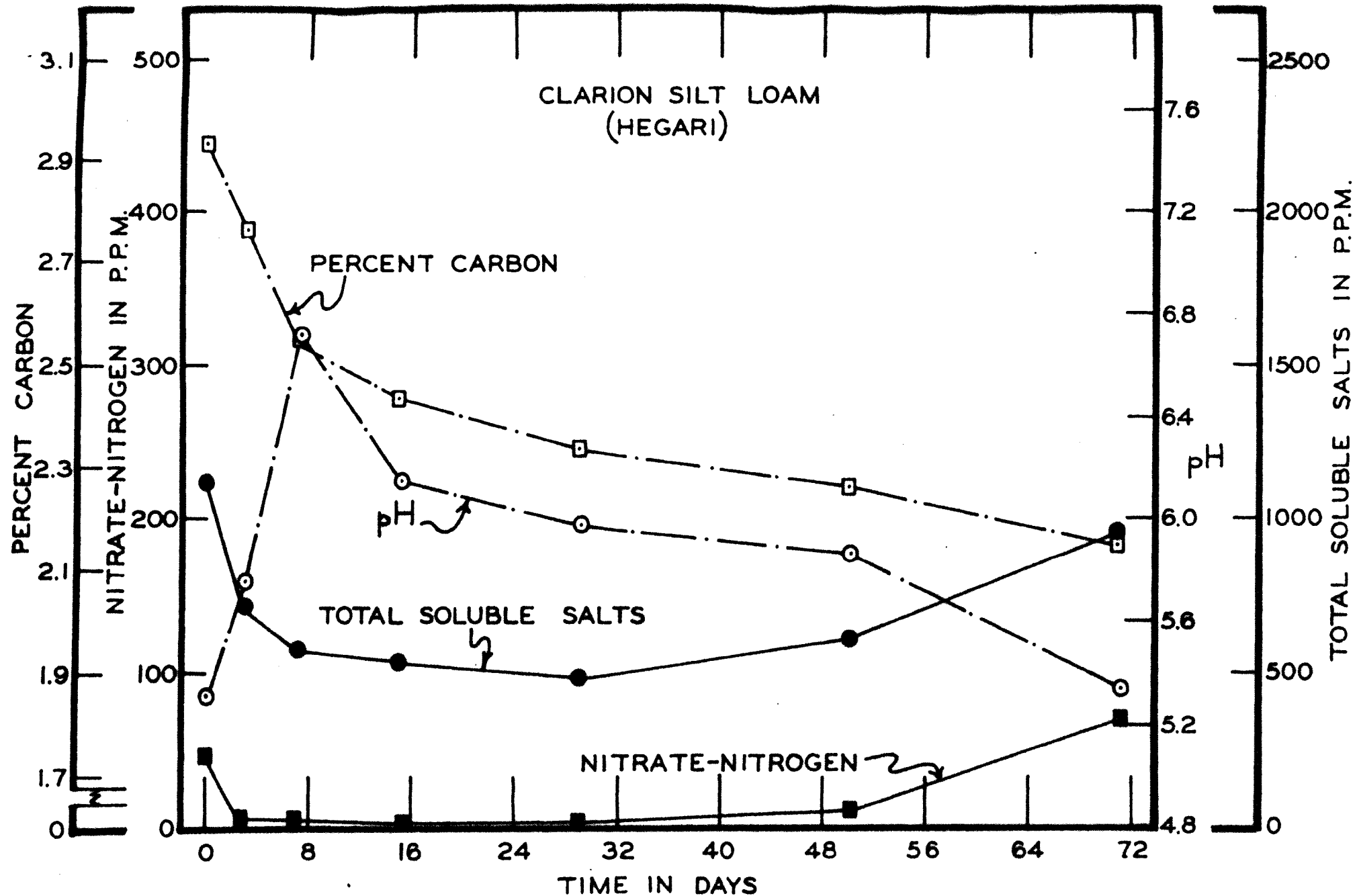
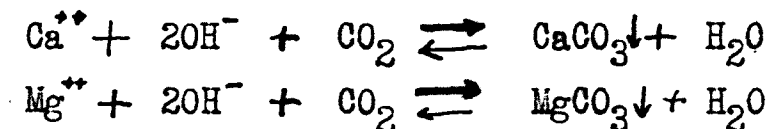


Fig. 15. Effect of the decomposition of hegari on the percent carbon, pH, nitrate-nitrogen and total soluble salt contents of samples of Clarion silt loam.

- (a) Utilization of nitrate by microorganisms.
- (b) Precipitation of calcium and magnesium carbonates as a result of carbon dioxide production, which could be illustrated by the following equations:



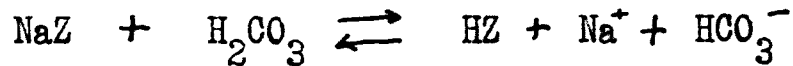
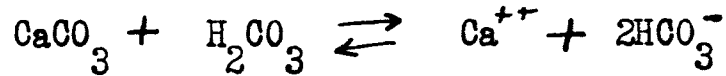
After the minimum value is reached for the total soluble salt contents, and the amount of soluble salts begins to increase, there are several changes which could possibly occur to account for this increase, such as:

- (a) Formation of large amounts of nitrates that account in a large measure for the observed increase in total soluble salts. This process, consisting of nitrification of ammonia (probably present in the soil as ammonium ion), could be represented as follows:



- (b) Liberation of large amounts of carbon dioxide (during the decomposition process) which acts on the carbonates and soil zeolites to produce more soluble salts. As far as the carbonates are concerned, they now dissolve, whereas during the initial stage they precipitated out.

These reactions may be illustrated by the following equations:



In Figures 10 and 11 it was observed that all of the plant materials caused a decrease in the percentage of particles less than 0.05 mm. in diameter, indicating aggregation of the smaller particles into larger water-stable aggregates. The aggregation increased with the time of incubation, although the greatest effect was produced during the initial decomposition period.

Contrary to expectations, the non-legumes in all soils tested caused a greater aggregation of the particles than did the leguminous plants, although the differences were usually not very great. In general, the influence of the various materials on aggregation decreased in the following order: Markton oats, hegari, sesbania, and sour clover. This agrees essentially with the work of Chapman (19), who reported that only 10.8% of the soil "crumbs" from a timothy-treated soil would pass through a 1/16 inch screen, whereas 55.7% of those from a clover-treated soil passed through.

The difference in the effect of legumes and non-legumes on the aggregation of soils has been considered,

but as yet no entirely logical explanation has been found. The chief difference in the composition of legumes and non-legumes (Table VI) is the high protein-nitrogen content of the legumes. This nitrogen was found to be quickly nitrified to nitric acid, which, because it tends to bring calcium into solution (42), would be expected to increase aggregation rather than decrease it, particularly in alkaline-calcareous soils. The inherently higher calcium contents of the leguminous plant materials (Table VI) should also assist in this process.

The mechanism of soil aggregation in all of its phases has never been clearly explained. It is known that two types of binding material are usually present in the soil; namely, the inorganic and the organic colloidal materials. Peele (43) divides the organic binding forces into (a) those forces consisting of the lyophobic colloids formed as part of the residues of the plant materials added to the soil, and (b) those forces resulting from the cells of microorganisms and their secretory products. He found that the microbial cells and their products were often one of the major binding forces in the aggregates of soil particles.

Martin and Waksman (33) also decided that the

bacterial decomposition products were important in aggregate formation. They concluded however, that the aggregation effect of the various organic materials varies not only with the organisms involved in the decomposition process, but also with the nature of the organic material added, which appears to be in agreement with the results obtained in this investigation.

It seems probable, however, that the amount of aggregation produced and the kind of aggregates formed depends upon the specific organic material originally added to the soil. The type of aggregate and its comparative stability is affected by a number of factors, such as (a) the nature of the binding materials used in forming the aggregates, (b) the kind of microorganisms present, and (c) the texture and moisture content of the soil.

In this investigation it is quite possible that the intermediate decomposition products of the non-leguminous plant materials resulted in the formation of more stable aggregates than those produced by the legumes, hence the apparent increase in the number of aggregates.

The apparent anomalies noted during the course of this investigation are worthy of further study, and suggest that a study of organic matter decomposition under field conditions is necessary for a complete elucidation of the problem.

SUMMARY AND CONCLUSIONS

1. A study was made under controlled, optimum conditions of the rate of decomposition of some commonly used leguminous and non-leguminous green manures, as well as their influence upon the physical and chemical properties of several alkaline-calcareous soils of Arizona and one acid soil from Iowa. For this purpose the crops used were sesbania, sour clover, hegari, and Markton oats. The Arizona soils studied were: Gila sandy loam, Pima clay loam, and Superstition sand; the acid soil from Iowa was Clarion silt loam. The effect of these plant materials upon the pH value, nitrate nitrogen, total soluble salt contents, and the degree of aggregation was quantitatively determined.
2. At the same temperature and comparable moisture conditions the rate of decomposition of each of the materials was most rapid in the acid Clarion silt loam and least rapid in the alkaline

Superstition sand. The carbon-nitrogen ratio of the added organic matter was found to have a pronounced effect upon its rate of decomposition in the alkaline calcareous soils, whereas the effect was negligible in the case of the highly organic acid soil.

3. The initial decomposition of the leguminous plant materials was more rapid than that of the non-leguminous materials in the alkaline-calcareous soils whereas in the acid Clarion silt loam, the rates were about equal. In the final stages of the decomposition however, a greater percentage of the carbon originally added by way of the non-legumes was oxidized than of that added in the form of leguminous materials. Sour clover was found to be an exception because of its high content of water soluble constituents which decomposed very quickly.
4. The addition of the organic materials caused a marked lowering of the pH in each of the alkaline-calcareous soils whereas no immediate effect was observed in the acid Clarion silt loam. Following the initial decrease in reaction, the pH value of all of the samples rose quickly and in the case of the non-legumes assumed a position close to that of the untreated samples. The legume-treated samples

assumed a pH value higher than that of the samples treated with hegari and Markton oats in the Superstition sand and Clarion silt loam since in these soils nitrification was not rapid and ammonia was allowed to accumulate.

When nitrates were formed, the reactions of all of the legume-treated soils became more acid.

5. Microorganisms bringing about the decomposition of the leguminous plant materials utilized all of the nitrates initially present in each soil tested. Upon further decomposition, however, large quantities of nitrates were formed in each soil, the amounts being in excess of those originally present. Nitrates quickly disappeared in all of the hegari and oats-treated samples and were not released even in amounts equivalent to those in the untreated samples for a period of 70 days.
6. All of the organic materials initially caused an increase in the water soluble contents of all the soil samples. Correlating with the initially rapid decomposition of the water-soluble fraction of the organic materials, a rapid decrease in the total soluble salt contents of the samples occurred. Thereafter, the salt content of the non-legume-treated samples remained at a value almost equivalent to that of the control samples. In the legume-

-treated samples, however, large increases in the amounts of total soluble salts occurred as a result of the increases in the nitrate contents.

7. The addition of organic materials was found to decrease the percentage of soil particles less than 0.05 mm. in diameter, indicating the formation of aggregates. The non-legumes caused a greater aggregation of the soil particles than the legumes in each soil tested. Markton oats caused a greater degree of aggregation than the hegari; and, of the leguminous plants, the sesbania was more effective than the sour clover.

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