Microbiological Studies of Some Typical Iowa Soil Profiles

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AGRONOMY SECTION

SOILS

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SUMMARY AND CONCLUSIONS

The determination of the numbers of bacteria, actinomycetes and molds in various horizons of typical profiles of some Iowa soils was made during two seasons and the results compared with careful descriptions of the soil profiles by horizons. The Carrington loam was sampled in typical profiles several times thru the season of 1926 in Buchanan County. The Lindley sandy loam was also sampled at different dates. In 1927 the Carrington loam, the Clyde silty clay loam and the Dickinson fine sandy loam were sampled in the same county at several dates during the early part of the season. In the same season the Marshall silt loam and the Knox silt loam were sampled at several different dates in typical profiles in Crawford county.

It is apparent from the results as a whole that the content of microorganisms decreased from the surface to the lower horizons in typical soil profiles of the various soil types. The largest numbers of bacteria appeared in either the A_1 or the A_2 horizon, and the largest numbers of actinomycetes likewise appeared in one or the other of these horizons. In the case of the molds, the largest numbers sometimes occurred in the third surface horizon. In all the soils, however, the most striking decreases occurred from the A_3 to the B horizon. Further decreases occurred from the B_1 to the B_2 horizon, from the B_2 to the C_1 horizon and from the C_1 to the C_2 horizon, but these decreases were relatively smaller. In the case of the molds the decreases in the lower soil horizons were usually relatively insignificant. The total decrease in numbers of molds from the surface soils to the lowest depths was relatively smaller than in the case of the bacteria and actinomycetes.

In some instances the variations in numbers of microorganisms in the three surface, or A horizons, were relatively small. In other cases, considerable decreases occurred from the A_1 to the A_2 or from the A_2 to the A_3 horizon.

The variations in the moisture content of the different soil layers in the samples studied seemed to have no definite relationship to the numbers of bacteria, actinomycetes or molds. In some cases, decreases in numbers of microorganisms occurred between layers in which the moisture content was very much the same. Increases in numbers of microorganisms frequently occurred along with decreases in moisture. Hence, while in a number of cases decreases in numbers corresponded with decreases in moisture, apparently the decreases were occasioned largely by other conditions in the soil.

The variations in moisture content seemed to be of the least significance in the lower soil layers, the numbers decreasing without regard to the variations in moisture content. In the surface soils there was sometimes an indication of a relation between the moisture content and the numbers of bacteria and actinomycetes.

With the higher moisture content there was sometimes a higher content of bacteria. This was not uniform, however, and the general conclusion must be drawn that the variations in numbers occur with little or no regard to slight variation in moisture conditions. It should be emphasized that the differences in moisture conditions in the various soils compared were not very large and probably other factors were of greater significance. With extremes of moisture, either a high content or a low content, the effect would undoubtedly have been more significant.

There were some indications of seasonal effect upon the numbers of microorganisms in the different soils studied, especially in Series I. The largest numbers of microorganisms, in general, seemed to occur in the early spring samplings and again in the early fall samplings. Low counts ordinarily appeared in the samples late in the fall. Indications of similar seasonal effects were noted in the soils studied in Series II and Series III, altho the samplings in these two cases were not carried over the entire season. The results, in general, do seem to confirm previous observations which have indicated larger numbers of microorganisms in the June and September samplings than in the samplings taken during the summer.

It should be noted further that variations in numbers of organisms, as affected by seasonal conditions, occurred only in the surface layers and were chiefly confined to the A_1, A_2 and A_3 horizons. No definite effect could be noted in the B or C horizon from seasonal variations. The seasonal effect appeared to be similar on the bacteria and actinomycetes, but there was little influence upon the mold content. It is quite possible that more extreme seasonal conditions than those which prevailed while these experiments were under way would have had a much larger influence on the numbers of microorganisms.

The soil type differences were reflected in some cases in the content of microorganisms in the various soil layers. Apparently the characteristic of the most significance was the content of organic matter or the color of the soil. Obviously, however, the texture of the soil was also of very large importance. Topography, the character of the subsoil and all other characteristics which serve to distinguish the soil type may play a part. The most striking relationship between the numbers of organisms present and the soil types studied was found in Series II. The Dickinson fine sandy loam, which is lighter in color than the Carrington loam and the Clyde silty clay loam, showed a lower content of microorganisms, especially bacteria and actinomycetes. Undoubtedly this was due in large part to the lower organic matter content of the soil. In Series III, the Knox silt loam was, in general, lower in numbers of bacteria and actinomycetes than the Marshall silt loam, again a difference which is probably due in large part to the variation in content of organic matter. Other factors, however, may be of quite as large significance in individual cases. Heavy-textured types, such as the Clyde silty clay loam, may actually be lower in content of microorganisms even tho they are blacker in color than soils which are not so heavy in texture. This was noted in the case of some of the comparisons between the Clyde silty clay loam and the Carrington loam. When the texture is very heavy, aeration undoubtedly is limited. The development of microorganisms may be hampered because of a lack of air, while the content of organic matter and the color of the soil may be such that a large number of microorganisms would be expected to be present.

The differences in content of microorganisms in the surface soil, as influenced by the type characteristics may or may not continue into the lower soil layers. In general there seemed to be little relationship between the variations in conditions in the subsoil and the content of microorganisms. The coarse textured subsoil of the Dickinson fine sandy loam had a larger content of microorganisms than did the Clyde silty clay loam or the Carrington loam, which have much larger numbers in the surface soils. Larger numbers of microörganisms were noted in some cases in the lower layers of the Knox silt loam, while the surface soil was lower in content of microorganisms than the surface soil of the Marshall silt loam.

Comparing the numbers of organisms in the subsoils of the loess types, the Marshall silt loam and the Knox silt loam, there seemed to be many more bacteria and actinomycetes than in the case of the soils of drift origin, the Carrington loam, the Clyde silty clay loam, the Dickinson fine sandy loam and the Lindley sandy loam. The earlier studies on numbers of bacteria in the Missouri loess soils, compared with those in Wisconsin drift soils, are largely confirmed by these data. The difference is undoubtedly due to differences in the physical conditions of the subsoils of the loess types and of the drift types, which are ordinarily very heavy and even impervious in texture There is a possibility that the difference in the lime content of the drift soils may also be of significance, altho no definite evidence along this line is indicated by these results. This may be one reason for the higher content of microorganisms in the lower layers of the Knox silt loam as compared with the Marshall silt loam.

Only one comparison gives any information regarding the effect of treatment on the numbers of microorganisms in the different soil layers. In Series I it appears that the cultivation of the Carrington loam had increased the numbers of microorganisms in the different layers to a considerable extent. The soil in virgin sod was found to be much lower in numbers of microorganisms thru the A horizon, and even down into the B and C horizons. At the lower depths, however, the effect of cultivation was not shown very distinctly. It is quite probable that differences in the characteristics of the lower soil layers would have more effect upon the content of microorganisms than the treatment of the surface soil. Extremes of soil treatment, such as applications of large amounts of farm manure, would undoubtedly very materially affect the content of microorganisms in the surface layers, and this difference might extend even down into the B horizon. Probably the texture of the soil would be of particular significance in determining the rapidity with which the lower soil layers are influenced by the treatment of the surface soil.

The relationships between the numbers of bacteria and the numbers of actinomycetes and molds were usually very similar in the different soils. The numbers of actinomycetes seemed to be affected in a very similar way to the numbers of bacteria, but in many instances the numbers of molds were affected in quite the opposite direction. Large increases in numbers of bacteria and actinomycetes occurred when decreases in the number of molds were found. The mold content of the soils was very low and the differences in mold count were often hardly large enough to be significant. Large numbers of actinomycetes were found in all the soils, but the total numbers were very much smaller than the total numbers of bacteria. In general, the decreases in the lower layers from the surface layers, were relatively less in the case of the actinomycetes and much less in the case of the molds than was true of the bacteria, which confirms earlier results.

In general, the results show striking decreases in the numbers of bacteria in the lower soil layers over those present in the surface soils. Variations in the decreases occurring between different horizons were often quite large, and they generally occurred without reference to differences in moisture. There is some evidence of seasonal effects, and there is some indication of an influence from long continuous soil treatment, but the chief factor which is probably responsible for these variations is the natural difference in the physical and chemical characteristics of the lower soil layers. Probably the most important is the difference in the organic matter content, which is reflected in the color of the soil. The texture, however, is also undoubtedly of large significance, particularly when fine textured types are compared with coarse textured soils. Probably all the characteristics which serve to distinguish the individual soil types have an influence on the content of microorganisms in the various soil layers. At least in two cases definite relationships between the soil types studied and the content of microorganisms are shown.

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The methods for the classification of soils, first suggested by the Russian pedologists and now, with certain modifications, being followed in all the soil survey work in this country, involve a consideration of the characteristics of the various horizons of soil profiles. It is becoming evident, however, that it is not sufficient merely to examine the profiles physically and in a rough chemical way, such as is done to provide the necessary data for the naming of the soils by series and types. Complete information is needed regarding the physical, chemical and biological characteristics of the different horizons of typical profiles of at least the more extensive types.

As Joffe (12) has pointed out, a number of investigations have been conducted in which studies have been made of the physical characteristics and the chemical composition of the various layers in certain soil profiles, but practically nothing has been done from a biological standpoint. It appears that a microbiological study of the horizons of typical profiles may throw considerable light on the problems involved in the nomenclature and classification of soils. It may also provide valuable information regarding the fertility requirements of soils and may explain the causes of certain occurrences which hitherto have not been understood.

It was the purpose of the work reported in the following pages to study the numbers of microorganisms in the various horizons of the profiles of some typical Iowa soils. Later, investigations will be made of the relationship of the microorganisms present to the characteristics of the various soil layers and chemical and physical studies will be carried out, with the biological. For the present, and somewhat as a preliminary to the rather complete study of soil profiles as planned, the data secured on numbers will be presented.

HISTORICAL

No investigations are reported in the literature which are directly comparable with the work given here. Many studies have been carried out on the numbers of microorganisms in soils at various depths, and some general conclusions have been drawn. A brief review of the more important work along this line will be given.

Koch (15) in 1881 first noted that the numbers of bacteria in soils decreased with depth. Proskauer (20) and Beumer (1) also noted decreases. Frankel (7), in a more careful study of numbers, found sudden and irregular changes at various depths down to two and one-half meters, sharp decreases sometimes occurring from one depth to the next. Fulles (8) concluded that two meters marked the depth to which most bacterial life extended. Others, however, have found numerous organisms present at much lower depths. Maggiora (18), Reimers (21), Houston (11), Caron (3), Stoklasa and Ernest (23), Kebrehl (13), Chester (4), King and Doryland (14), Waite and Squires (24), Eberbach (5), Miquel (19), Eisenhut (6), Greaves (9), Brown (2), Waksman (25), Lipman (16, 17), Greaves and Carter (10), and Snow (22) have all reported on the numbers of bacteria at different depths in soils. In most cases, however, the soil type was not known or at least was not specified in the work, and in some cases the soil conditions are not very clearly described. Likewise, the media used by the various investigators were different and, hence, the results secured cannot be compared.

It seems evident from the data available that the greatest numbers of bacteria occur near the surface of the soil. Waksman (25) found the greatest numbers one inch below the surface in shaded soil, while in garden soil the greatest numbers were four inches below the surface. Brown (2) secured the largest numbers at a depth of four inches in Carrington loam and also in Marshall silt loam, the areas in both cases being in cultivated crops. The greatest decreases occurred in the first eight or first 12 inches. Waksman noted a rather regular decrease from one or four inches to a depth of 30 inches, the greatest decrease occurring between the first and fourth or fourth and eighth inches. Lipman (16, 17) noted that bacteria penetrate deeper in arid soils than in humid soils, and he found that bacterial activities may be greater at 24 inches than at six inches in some cases. Snow (22) found the greatest numbers at 12 inches in a wind-blown soil. Greaves (9) reports the largest numbers at two feet in irrigated soils.

In general it appears that while bacterial numbers usually decrease in soils at greater depths, the horizon showing the largest numbers and the decreases from horizon to horizon in any profile may vary widely. It seems probable, therefore, that the numbers of microorganisms in the various soil layers of a type profile may reflect more or less definitely the characteristics of the horizons and, hence, of the entire profile.

EXPERIMENTAL

The work reported in the following pages was carried out on some typical Iowa soils occurring in Buchanan and Crawford counties. Samples were drawn from the various horizons with the usual precautions, pits having been dug in each case and the samples taken at the proper depths from the vertical walls. The samples were taken to temporary laboratories, which were set up in each county, and infusions, dilutions and platings made in the usual way. The plates were incubated at room temperature and the numbers of molds, actinomycetes and bacteria counted. The moisture content of the soils was determined and the numbers present were calculated on an air-dry basis.

The media used included Brown's egg albumen agar for the bacteria and actinomycetes and Waksman's synthetic acid mold medium for the molds. The composition of these media was as follows:

EGG ALBUMEN AGAR:

Dextrose	10.0 gms.
K_2HPO_4	0.5 gm.
$MgSO_4$	0.2 gm.
$Fe_2(SO_4)_3$	trace
Egg albumen	0.25 gm.
Distilled H_2O	1000 cc.
Reaction adjusted to pH 7.0.	
Agar	15.0 gms.

SYNTHETIC ACID MOLD MEDIUM:

Glucose	10.0 gms.
Peptone	5.0 gms.
KH_2PO_4	1.0 gm.
$MgSO_4$	0.5 gm.
Distilled H_2O	1000 cc.
Reaction adjusted to pH 3.6.	
Agar	25.0 gms.

The results secured in 1926 in Buchanan County are given in Series I, in Buchanan County in 1927 in Series II, and in Crawford County in 1927 in Series III.

SERIES I.

During the first season samplings were made of typical profiles of Carrington loam in cultivated areas on June 20, June 25, July 23, Aug. 25, Sept. 20, Oct. 21, and Nov. 11, of a typical virgin Carrington loam on June 20, and of profiles of Lindley sandy loam on Sept. 20, Oct. 21, and Nov. 11.

At each sampling careful descriptions were made of the profiles studied. Figure 1 shows three of these profiles in graphic form, the cultivated Carrington loam, the virgin Carrington loam and the Lindley sandy loam. The complete descriptions are given below:

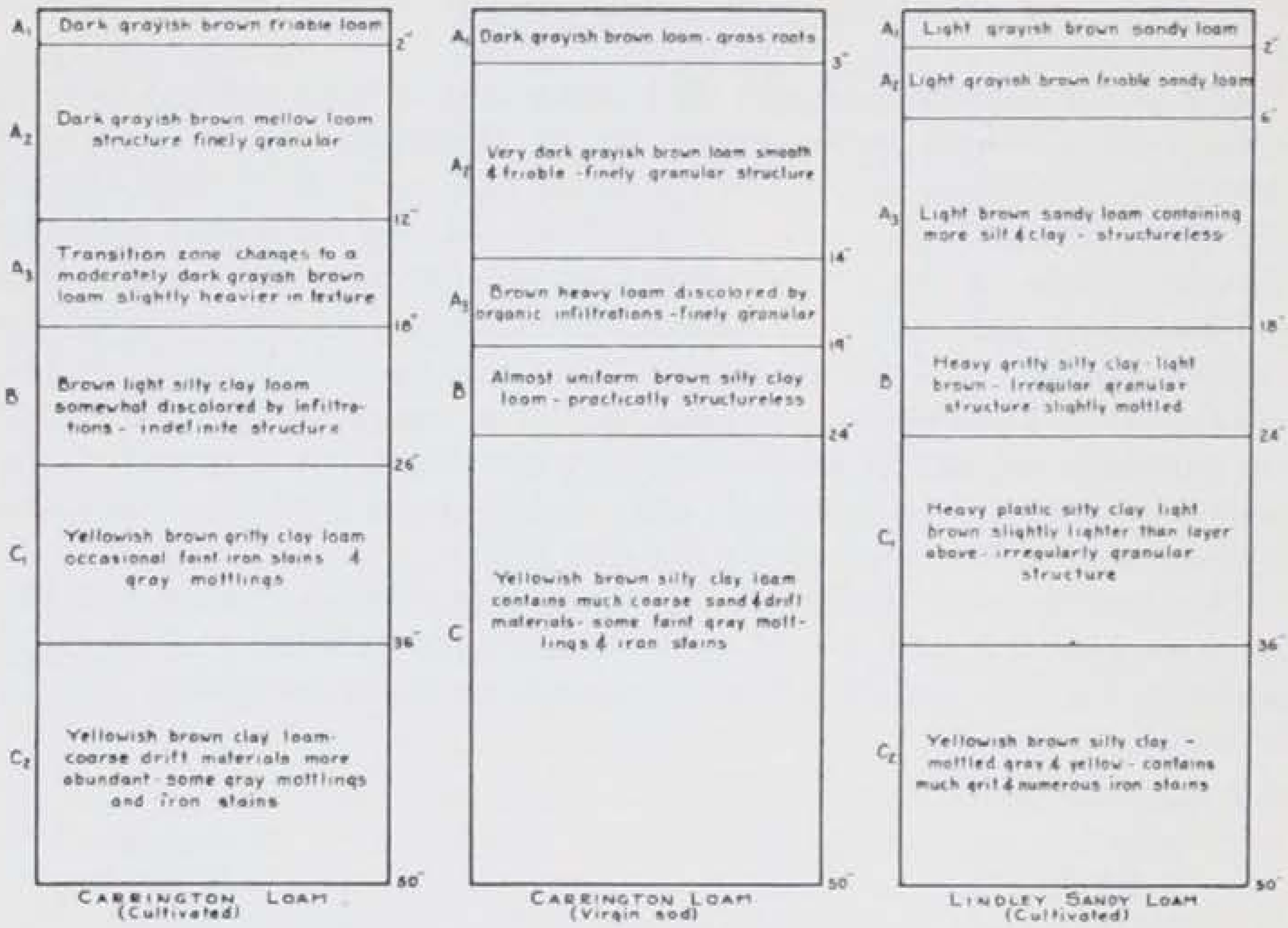

Fig. 1. Typical profiles of cultivated Carrington loam, virgin Carrington loam and Lindley sandy loam.

Carrington loam, No. 1, (Cultivated).

A_1 (0-2")—Very dark grayish-brown friable loam, containing considerable fine sand. When wet, the soil appears very dark brown to almost black. The structure is finely granular.

A_2 (2-12")—Very dark grayish-brown mellow loam. The color seems uniform. The soil has a high percent of silt and a fine granular structure.

A_3 (12-18")—Transition zone. The color changes from a very dark grayish-brown to a moderately dark grayish-brown. The soil is somewhat heavier in texture and almost a silty clay loam. It is friable and granular in structure.

B (18-26")—Brown light silty clay loam, friable, and discolored somewhat by organic infiltrations. The structure approaches finely granular.

C_1 (26-36")—Yellowish-brown gritty clay loam, not as heavy as the layer above; seems more friable and crumbly. A few faint organic infiltrations are present. Iron stains occur but are faint. Pieces of small gravel are found infrequently with considerable coarse and fine sand, which forms only a small percentage of the total soil layer. Faint gray mottlings are noticeable.

C_2 (36-50") —Yellowish-brown clay loam, quite gritty, with gray splotches and abundant iron stains. Coarse drift material is more abundant in this layer. Much like the layer above in color except that more iron stains are present.

Carrington loam, No. 2 (virgin).

A_1 (0-2")—Very dark grayish-brown smooth friable loam, filled with a dense mass of grass roots. When wet the soil appears dark brown to almost black. It has a medium granular structure, the granules clinging to the grass roots.

A_2 (2-14")—Very dark grayish-brown mellow loam, smooth and friable, indicating a considerable amount of silt and very fine sand. Grains of coarse sand occur with an occasional piece of small glacial gravel. Organic infiltrations give the soil an almost black appearance when wet. When dry the soil is grayish-brown in color.

A_3 (14-19")—Brown heavy loam to light silty clay loam, but so affected by organic matter that it has the appearance of a dark grayish-brown. Some light colored soil has been brought up thru worm burrows. The structure is finely granular to 16 inches and then becomes looser.

B (19-24")—The soil is more uniformly brown in color than above. The texture is a silty clay loam, discolored considerably by infiltrations of organic matter. A few grass roots are present. Almost structureless, tending to be finely granular, very pulverulent.

C (24-50")—Yellowish-brown silty clay loam, practically structureless but tending to be finely granular. The color is almost solid. Some organic infiltrations occur, faint gray mottlings and iron stains, gradually becoming more pronounced with depth. The layer is quite gritty, containing considerable coarse sand and some gravel. Rotten greenstone, small black coarse sand deposits and other drift materials, with an occasional small boulder are found. Below 50 inches the mottling becomes very pronounced with gray splotches and many orange-brown iron stains. The soil was in virgin sod and had apparently never been cultivated.

Carrington loam, No. 3 (cultivated).

A_1 (0-2")—Dark to moderately dark grayish-brown coarse loam.

A_2 (2-6")—Dark grayish-brown, friable loam, containing considerable coarse sand. Granular in structure.

A_3 (6-16")—Dark grayish-brown friable loam. A shade lighter than the surface six or seven inches.

B (16-25")—Transition zone. Brown friable heavy loam or silty clay loam. Organic infiltrations have changed the color of the basic soil horizon. Crushed between the fingers, the soil shows the true basic color—brown.

C_1 (25-32")—Dull yellowish-brown silty clay loam. Structureless; breaks up into irregular pieces, one-eighth to one-half of an inch in size. Quite gritty. More coarse material in the soil than ordinary, but it is very sticky.

C_2 (32-50")—Yellowish-brown silty clay loam slightly lighter in color than the horizon above. Contains much coarse drift material. Occasionally small granite boulders are found.

Carrington loam, No. 4 (cultivated).

A_1 (0-2")—Dark grayish-brown friable loam, finely granular in structure.

A_2 (2-6")—Dark grayish-brown friable loam, containing much silt and fine sand.

A_3 (6-14")—Dark grayish-brown friable loam with a high percent of silt.

B (14-24")—Transition zone. Brown silty clay loam, having a dark appearance due to infiltrations of organic matter. Color not solid. Friable, tends to form coarse irregular granules. Structure not well defined.

C_1 (24-33")—Dull yellowish-brown silty clay containing the usual coarse sand, occasional rock fragments and drift materials. Structureless.

C_2 (33-50")—Yellowish-brown silty clay loam to silty clay. A faint shade lighter than the horizon above. Drift material more abundant than above. Structureless.

Carrington loam, No. 5 (cultivated).

A_1 (0-2")—Dark to moderately dark grayish-brown loam, containing considerable fine sand. Finely granular in structure.

A_2 (2-6")—Very dark grayish-brown friable loam, high in silt. Seems somewhat heavy.

A_3 (6-14")—Very dark brown friable loam containing a high percentage of silt and clay.

B (14-20")—Transition zone. Dark brown light silty clay loam. A minimum amount of fine and coarse sand present. No structure. Organic infiltrations.

C_1 (20-34")—Dull yellowish-brown silty clay loam to silty clay. Color uniform. An occasional trace of organic infiltration is seen.

C_2 (34-50")—Dull yellowish-brown silty clay, sticky and plastic. Some increase in content of drift material, at the lower depths. In some small spots, one to three inches in diameter there are gritty drift accumulations of coarse sand and rock particles.

Carrington loam, No. 6 (cultivated).

A_1 (0-2")—Dark grayish-brown to grayish-brown loam.

A_2 (2-6")—Dark grayish-brown friable loam, containing considerable silt and sand. Granular.

A_3 (6-12")—Dark grayish-brown uniform loam, containing a high percentage of silt and fine sand. Coarse sand and an occasional pebble are found.

B (12-19")—Moderately dark grayish-brown heavy loam with the usual drift constituents. Some organic infiltrations from above. No structure.

C_1 (19-32")—Dull yellowish-brown gritty silty clay loam. Some organic infiltrations. Color uniform.

C_2 (32-50")—Yellowish brown silty clay loam to silty clay. Slightly heavier than the horizon above. Drift materials rather uniformly distributed thru the two layers.

Carrington loam, No. 7 (cultivated).

A_1 (0-2")—Moderately dark grayish-brown loam, finely granular in structure. Considerable coarse sand at the surface.

A_2 (2-6")—Moderately dark grayish-brown friable loam, finely granular in structure.

A_3 (6-15")—Moderately dark grayish-brown loam, containing considerable grit, uniformly distributed.

B (15-26")—Brown light clay loam. Friable. Darkened with much organic infiltration. Color not solid. Granulation irregular.

C_1 (26-35")—Yellowish-brown gritty silty clay loam. Contains a few faint mottlings of gray. Structureless.

C_2 (35-50")—Yellowish-brown gritty silty clay loam. Contains much coarse and fine sand and occasional glacial pebbles. Small granite boulders occur infrequently.

Carrington loam, No. 8 (cultivated).

A_1 (0-2")—Dark grayish-brown loam, finely granular.

A_2 (2-6")—Dark grayish-brown loam, friable with granular structure. High in organic matter.

A_3 (6-18")—Dark grayish-brown heavy loam, friable, granular in structure. High in organic matter.

B (18-28")—Brown silty clay loam. Organic infiltrations give a dark appearance.

C_1 (28-38")—Yellowish-brown silty clay loam to silty clay. Uniform in texture and color. Drift materials occur uniformly distributed. Small pieces of gravel occur.

C_2 (38-50")—Yellowish-brown gritty silty clay, slightly heavier than horizon above. Faint gray mottlings occur infrequently. Some iron stains are found.

Carrington loam, No. 9 (cultivated).

A_1 (0-2")—Moderately dark brown or dark grayish-brown loam, finely granular in structure.

A_2 (2-6")—Moderately dark grayish-brown loam, friable, finely granular in structure.

A_3 (6-16")—Moderately dark grayish-brown friable loam. Structure finely granular to granular.

B (16-24")—Dark brown silty clay loam, colored by organic infiltrations. Transition zone. No structure.

C_1 (24-35")—Yellowish-brown gritty clay loam. Much drift material thruout horizon.

C_2 (35-50")—Yellowish-brown gritty clay loam, similar to the layer above but having more grit and a few faint gray mottlings. No structure.

Lindley sandy loam, No. 10 (cultivated).

A_1 (0-2")—Light grayish-brown sandy loam containing a high percentage of fine sand and some small gravel scattered over the surface. Single grain structure.

A_2 (2-6")—Light grayish-brown friable sandy loam, containing some brown and dark brown organic coloration in occasional fine streaks or thread-like lines, but very faint.

A_3 (6-18")—Light brown sandy loam, containing more silt and clay than the upper horizons. Structureless. Streaks of gray and brown—not true mottling.

B (18-24")—Heavy gritty silty clay. Light brown in color with a few gray and brown mottlings. Irregular granular structure.

C_1 (24-36")—Heavy plastic silty clay. Light brown in color, containing a few gray and brown mottlings. Considerable coarse sand and fine rock particles. Some iron stains. Irregular granular structure.

C_2 (36-50")—Yellowish-brown silty clay or clay, mottled with gray and yellow. Contains much grit, coarse sand and gravel. Numerous iron stains. Irregular granules and plates show indefinite structure.

Carrington loam, No. 11 (cultivated).

A_1 (0-2")—Dark grayish-brown loam.

A_2 (2-6")—Dark grayish-brown loam, much like surface horizon.

A_3 (6-14")—Dark grayish-brown loam. These three horizons contain considerable coarse sand, fine sand and a few pieces of small rock and gravel.

B (14-21")—Transition zone. Brown to dark brown heavy loam to silty clay loam. Color not solid. Some organic infiltrations.

C_1 (21-27")—Brown light clay loam, slightly heavier than horizon above. Discolored somewhat by organic infiltrations.

C_2 (27-50")—Yellowish-brown silty clay loam, containing much grit, coarse and fine sand and small glacial gravel. Small glacial boulders frequently occur. Faint gray mottlings.

Lindley sandy loam, No. 12 (cultivated).

A_1 (0-2")—Light grayish-brown or gray sandy loam. Structureless.

A_2 (2-6")—Light brown or grayish-brown sandy loam, containing considerable silt. Single grain structure.

A_3 (6-14")—Light brown sandy loam, containing a high percentage of silt. Structureless. Fairly uniform in texture. Some coarse sand and glacial gravel scattered thru the horizon.

B (14-21")—Transition zone. Light brown or yellowish-brown gritty heavy silty clay loam, containing considerable silt. Faint gray mottlings occur. Coarsely granular in structure.

C_1 (21-27")—Heavy plastic silty clay, yellowish-brown in color, containing much grit, coarse sand and fine sand and a few gravel particles. Brown and gray mottlings. Structure indefinite. Tends to form platey and irregular granules.

C_2 (27-50")—Yellowish-brown, gritty clay highly mottled with gray, yellow and brown. Some iron stains. Contains an abundance of coarse sand, fine sand and gravel.

Carrington loam, No. 13 (cultivated).

A_1 (0-2")—Dark grayish-brown friable loam, containing much coarse sand. Finely granular in structure.

A_2 (2-6")—Dark grayish-brown friable loam.

A_3 (6-15")—Dark grayish-brown loam, slightly heavier in texture than horizons above and contains more silt. Finely granular in structure.

B (15-18")—Grayish-brown loam to silty clay loam, friable, granular structure. Transition zone. Colored strongly with organic infiltrations.

C_1 (18-32")—Dull yellowish-brown silty clay loam. Contains considerable grit. Color uniform and solid.

C_2 (32-50")—Yellowish-brown gritty silty clay loam to silty clay. Lighter in color than horizon above. More grit present. A few faint gray mottlings.

Lindley sandy loam, No. 14 (cultivated).

A_1 (0-2")—Grayish-brown sandy loam, containing much fine sand and silt. Single grain structure.

A_2 (2-6")—Yellowish-brown or grayish-brown sandy loam, containing much fine sand and silt. Single grain structure.

A_3 (6-15")—Yellowish-brown sandy loam, containing much fine sand and silt. Uniform in texture and structure.

B (15-18")—Transition zone. Yellowish-brown gritty loam, containing a high percent of silt and clay. Structure irregular and coarsely granular.

C_1 (18-32")—Yellowish-brown gritty clay loam. Coarsely granular, granulation irregular and somewhat indefinite.

C_2 (32-50")—Very tough gritty silty clay, occasional gray mottlings and streaks. A few iron stains or streaks with numerous iron nodules occur. Much grit and glacial gravel are present.

TABLE I. MICROORGANISMS IN SOME SOIL PROFILES IN IOWA

Soil type and date sampled	Depth soil horizon	Percent H_2O	Bacteria per gram air-dry soil	Actino-mycetes per gram air-dry soil	**Molds per gram air-dry soil**
Carrington loam	A_1(0-2")	9.0	8,630,000	770 000	**17,100**
Number 1	A_2(2"-12")	16.0	5,710,000	710,000	**17,300**
(cultivated)	A_3(12"-18")	15.0	3,650,000	700,000	**15,500**
June 20, 1926	B (18"-26")	14.0	372,000	40,000	**560**
	C_1(26"-36")	13.0	42,900	32,000	**520**
	C_2(36"-50")	14.0	4,380	———	**53**
Carrington loam	A_1(0-2")	6.0	3,636,000	425,000	**11,700**
Number 2	A_2(2"-14")	8.0	4,565,000	652,000	**10,300**
(virgin sod)	A_3(14"-19")	9.0	3,510,000	582,000	**9,450**
June 20, 1926	B(19"-24")	10.0	730,000	44,000	**2,610**
	C (24"-50")	11.0	4,300	33	**190**
Carrington loam	A_1(0-2")	7.0	4,190,000	1,070,000	**21,500**
Number 3	A_2(2"-6")	10.0	5,000,000	900,000	**16,600**
(cultivated)	A_3(6"-16")	12.0	4,660,000	680,000	**13,800**
June 25, 1926	B (16"-25")	14.0	837,000	93,000	**1,390**
	C_1(25"-32")	16.0	37,000	5,000	**470**
	C_2(32"-50")	17.0	7,100	840	**72**
Carrington loam	A_1(0-2")	9.0	4,725,000	988,000	**17,500**
Number 4	A_2(2"-6")	11.0	4,740,000	809,000	**17,900**
(cultivated)	A_3(6"-14")	11.0	4,440,000	560,000	**11,700**
June 25, 1926	B (14"-24")	17.0	614,000	84,000	**2,160**
	C_1(24"-33")	18.0	36,500	6,000	**720**
	C_2(33"-50")	17.0	7,710	730	**48**
Carrington loam	A_1(0-2")	12.0	3,300,000	909,000	**29,500**
Number 5	A_2(2"-6")	16.0	3,900,000	1,070.000	**28,500**
(cultivated)	A_3(6"-14")	17.0	3,700,000	590,000	**16,800**
July 23, 1926	B (14"-20")	17.0	687,000	204,000	**2,000**
	C_1(20"-34")	16.0	26,500	4,760	**1,900**
	C_2(34"-50")	15.0	5,000	705	**294**
Carrington loam	A_1(0-2")	10.0	3,550,000	660,000	**21,100**
Number 6	A_2(2"-6")	11.0	4,720,000	590,000	**18,600**
(cultivated)	A_3(6"-12")	12.0	4,900,000	610,000	**16,000**
July 23, 1926	B (12"-19")	13.0	356,000	69,000	**1,700**
	C_1(19"-32")	16.0	17,800	5,400	**590**
	C_2(32"-50")	17.0	2,860	1,370	**250**
Carrington loam	A_1(0-2")	11.0	3,146,000	560,000	**26,900**
Number 7	A_2(2"-6")	15.0	2,059,000	529,000	**25,800**
(cultivated)	A_3(6"-15")	16.0	2,500,000	476,000	**18,900**
Aug. 25, 1926	B (15"-26")	18.0	414,000	134,000	**2,300**
	C_1(26"-35")	19.0	24,600	3,700	**860**
	C_2(35"-50")	19.0	5,300	240	**220**
Carrington loam	A_1(0-2")	15.0	4,101,000	700,000	**23,500**
Number 8	A_2(2"-6")	17.0	4,337,000	600,000	**21,600**
(cultivated)	A_3(6"-18")	20.0	3,625,000	560,000	**17,500**
Aug. 25, 1926	B (18"-28")	19.0	456,000	148,000	**1,480**
	C_1(28"-38")	18.0	72,900	4,260	**1,460**
	C_2(38"-50")	18.0	6,590	850	**207**
Carrington loam	A_1(0-2")	10.0	4,330,000	880,000	**25,500**
Number 9	A_2(2"-6")	12.0	4,880,000	790,000	**22,700**
(cultivated)	A_3(6"-16")	15.0	4,000,000	580,000	**17,600**
Sept. 20, 1926	B (16"-24")	16.0	309,000	35,000	**1,900**
	C_1(24"-35")	17.0	38,500	4,800	**1,320**
	C_2(35"-50")	17.0	7,600	830	**325**
Lindley sandy loam	A_1(0-2")	5.0	3,580,000	631,000	**16,800**
Number 10	A_2(2"-6")	8.0	3,910,000	543,000	**22,700**
(cultivated)	A_3(6"-18")	10.0	3,440,000	550,000	**13,300**
Sept. 20, 1926	B (18"-24")	10.0	466,000	22,200	**2,000**
	C_1(24 '36")	16.0	33,700	4,650	**1,620**
	C_2(36"-50")	15.0	9,500	580	**130**

TABLE I—Continued

Soil type and date sampled	Depth soil horizon	Percent H_2O	Bacteria per gram air-dry soil	Actinomycetes per gram air-dry soil	Molds per gram air-dry soil
Carrington loam Number 11 (cultivated) Oct. 21, 1926	A_1(0-2")	11.0	3,370,000	560,000	19,100
	A_2(2"-6")	12.0	3,630,000	569,000	18,100
	A_3(6"-14")	16.0	3,330,000	410,000	11,900
	B (14"-21")	14.0	510,000	116,000	1,390
	C_1(21"-27")	16.0	57,000	5,900	470
	C_2(27"-50")	15.0	6,230	235	153
Lindley sandy loam Number 12 (cultivated) Oct. 21, 1926	A_1(C-2")	8.0	3,600,000	430,000	15,200
	A_2(2"-6")	9.0	3,840,000	656,000	17,500
	A_3(6'-14")	11.0	3,480,000	449,000	17,400
	B (14"-21")	12.0	545,000	79,500	2,100
	C_1(21"-27")	17.0	47,000	7,200	720
	C_2(27"-50")	15.0	7,500	350	200
Carrington loam Number 13 (cultivated) Nov. 11, 1926	A_1(0-2")	16.0	5,119,000	950,000	23,800
	A_2(2"-6")	19.0	5,000,000	1,110,000	25,900
	A_3(6"-15")	20.0	4,125,000	1,000,000	13,700
	B (15"-18")	17.0	237,000	151,000	1,920
	C_1(18"-32")	13.0	59,800	10,000	2,520
	C_2(32"-50")	12.0	2,100	1,930	204
Lindley sandy loam Number 14 (cultivated) Nov 11 1926	A_1(0-2")	7.0	5,270,000	1,180,000	12,900
	A_2(2"-6")	9.0	4,830,000	990,000	25,200
	A_3(6"-15")	10.0	4,060,000	660,000	40 000
	B (15"-18")	10.0	751,000	110,000	3,110
	C_1(18"-32")	18.0	60,000	6,800	2,920
	C_2(32"-50")	15.0	12,000	1,130	236

Results of Microbiological Studies

The results of the microbiological studies on these soils are given in table I. The data are also shown graphically in Figs. 2 and 3 for the bacteria, 4 and 5 for the actinomycetes and 6 and 7 for the molds.

DEPTH

When the results given in the table and the graphs shown in the figures are studied, the striking decreases in numbers of bacteria, actinomycetes and molds from the surface to the lower depths in the various soil samples are very definitely shown. In general the decreases were rapid from the surface soil down to the depth of 50 inches or thru the C_2 horizon. In some of the Carrington loam samples, the numbers of bacteria were greater at the second depth or A_2 horizon than in the surface two inches or A_1 horizon. In the case of No. 1, sampled on June 20, 1926, there was a very much larger number of bacteria in the surface horizon. In No. 7, sampled on Aug. 25, the highest content of bacteria occurred in the surface horizon, and in No. 13, sampled on Nov. 11, there was a slightly greater number in the A_1 horizon. In general it appears, therefore, that the largest numbers of organ-

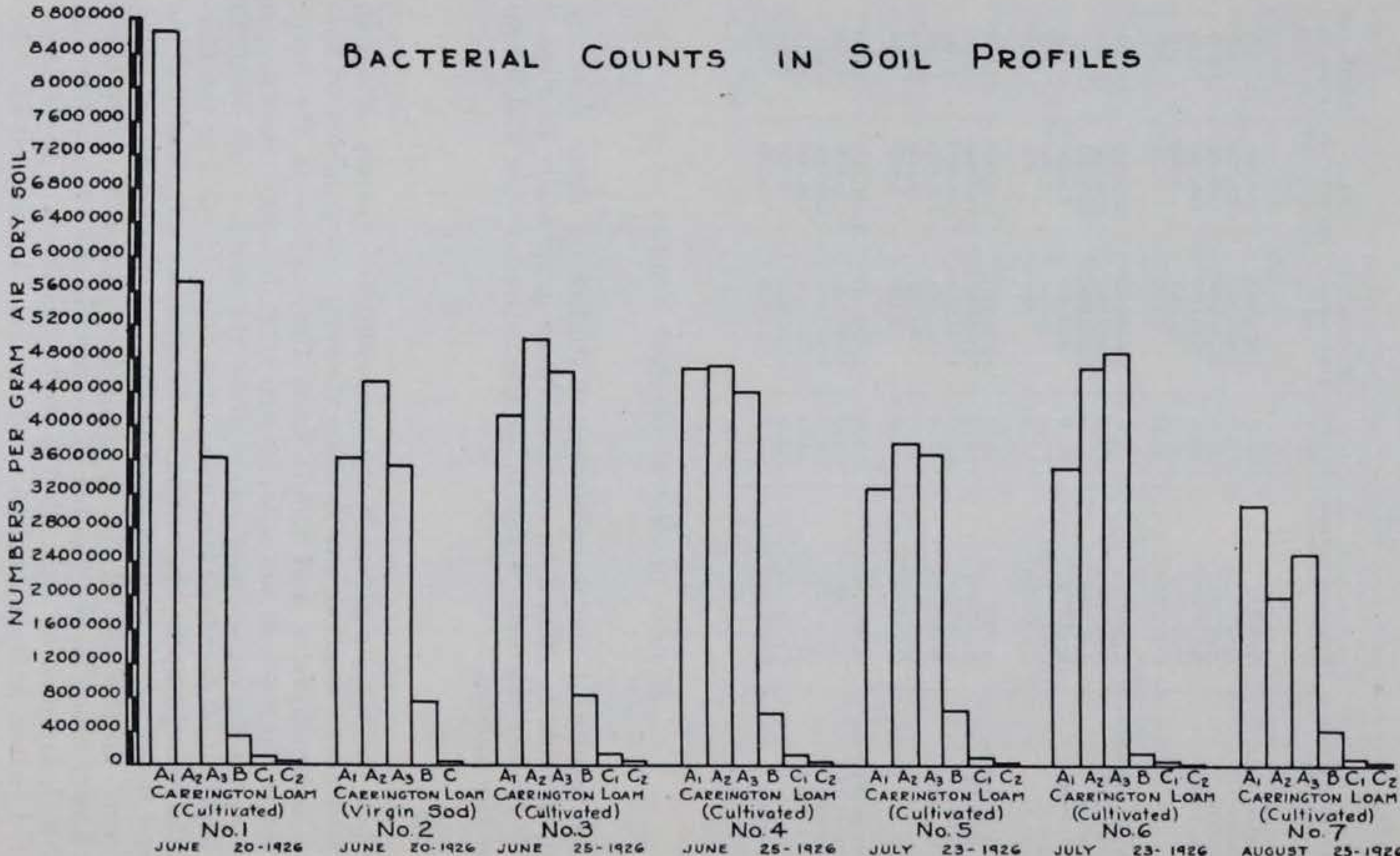

Fig. 2. Bacterial counts in soil profiles—series I.

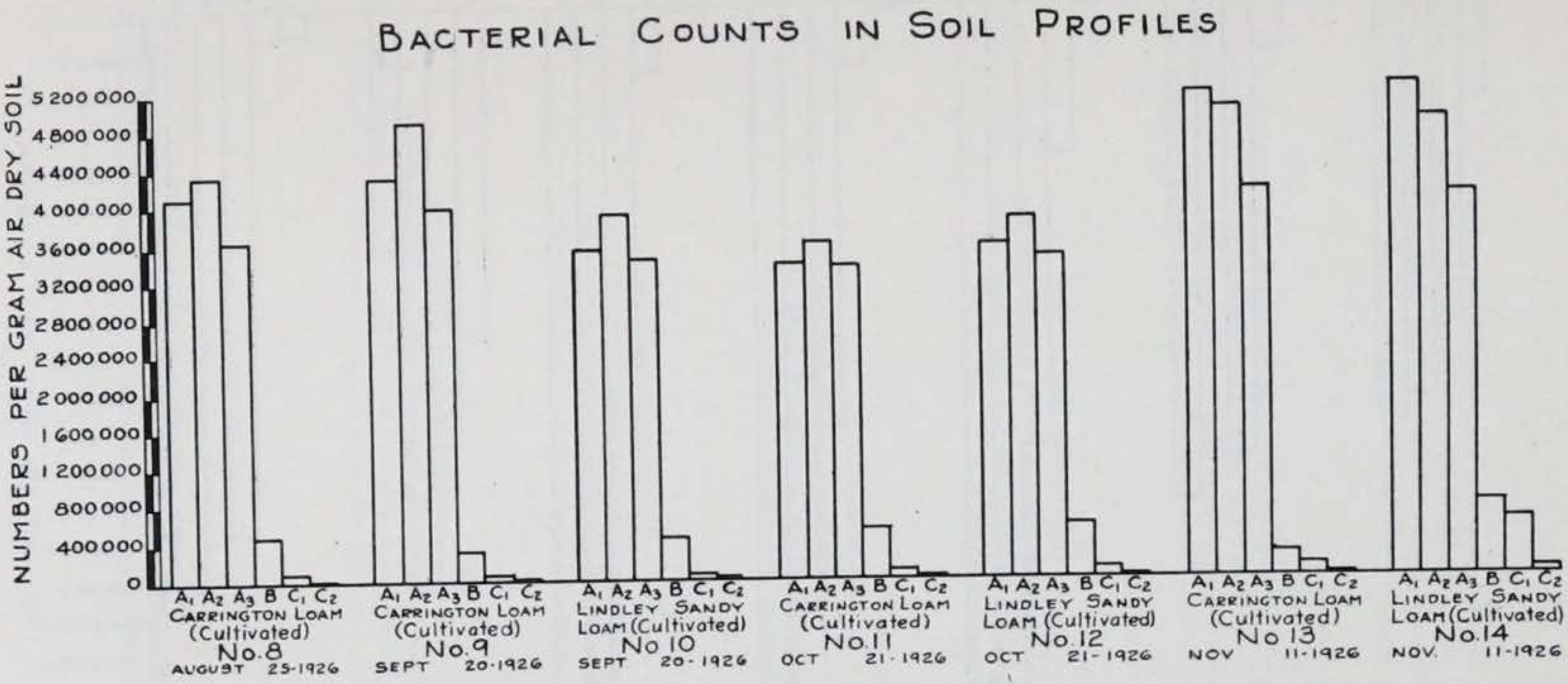

Fig. 3. Bacterial counts in soil profiles—series I. (Cont.)

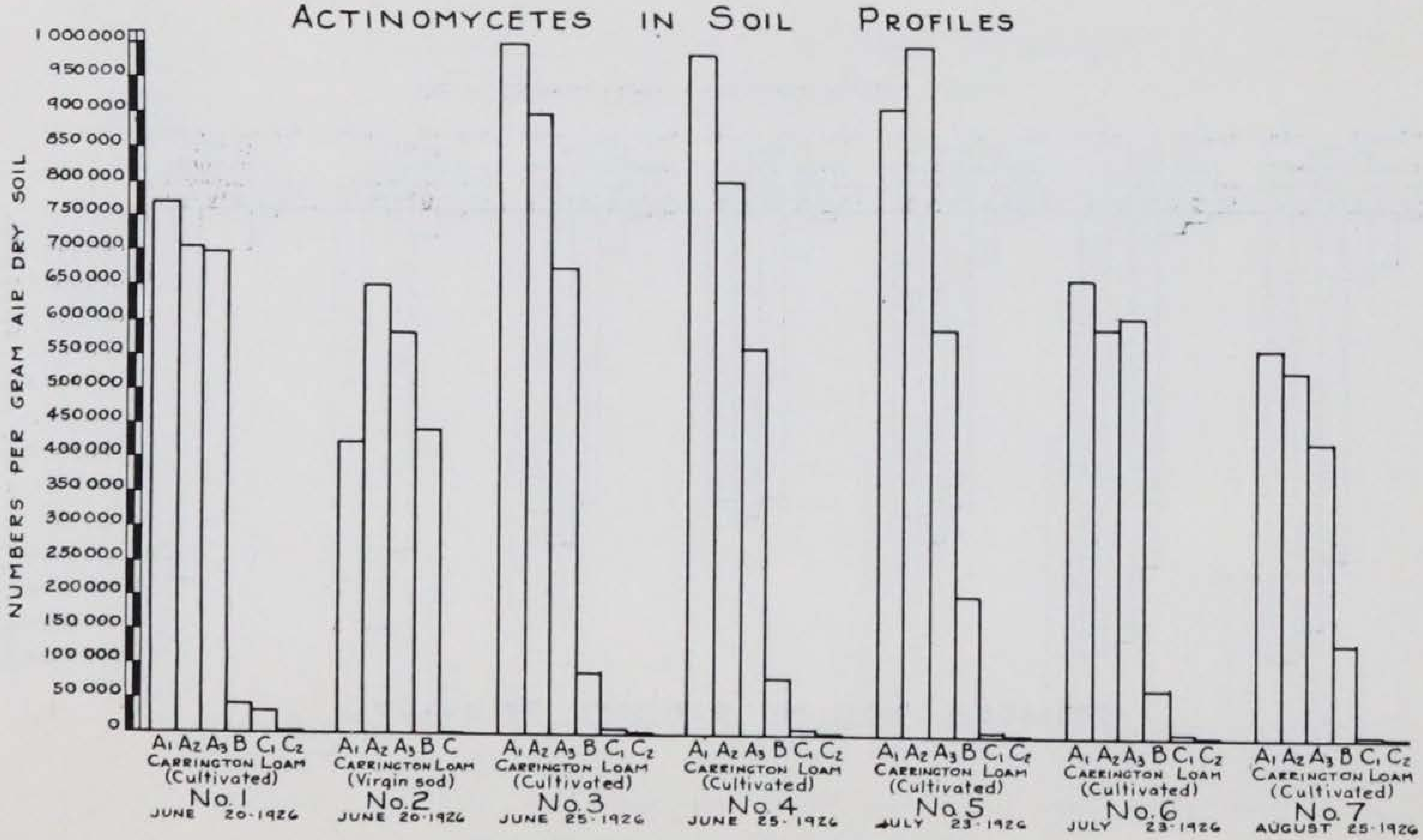

Fig. 4. Actinomycetes in soil profiles—series I.

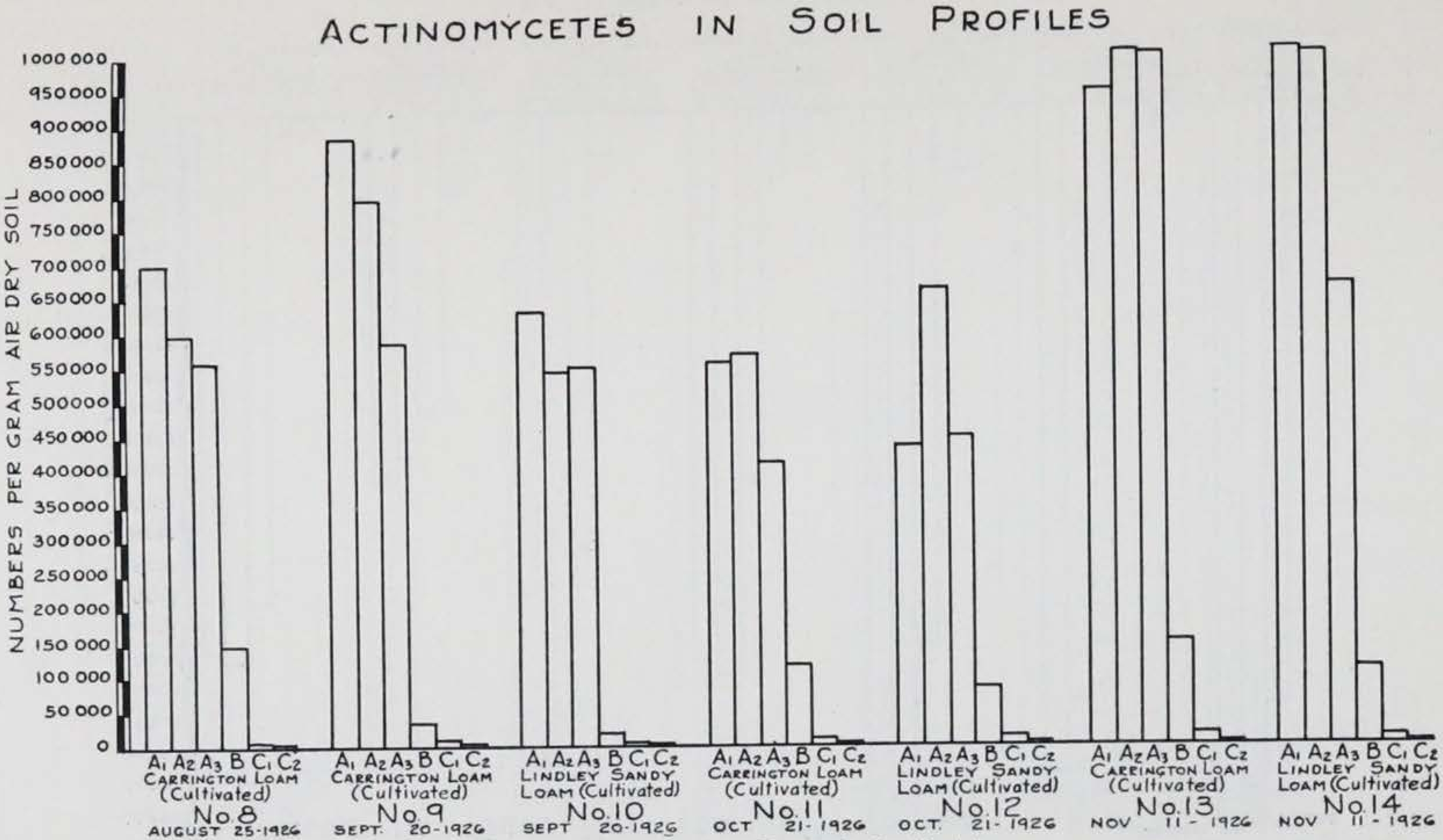

Fig. 5. Actinomycetes in soil profiles—series I. (Cont.)

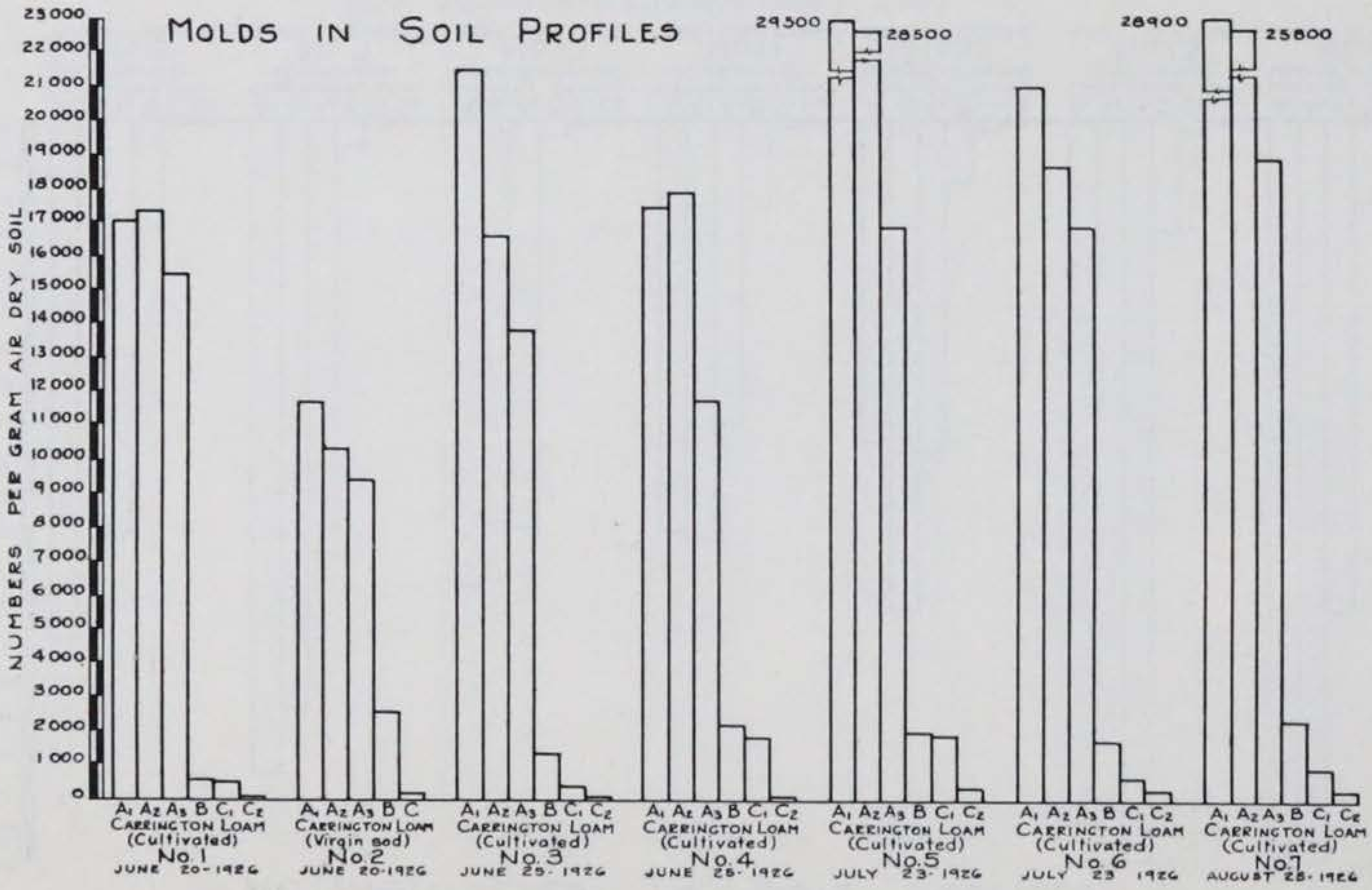

Fig. 6. Molds in soil profiles—series I.

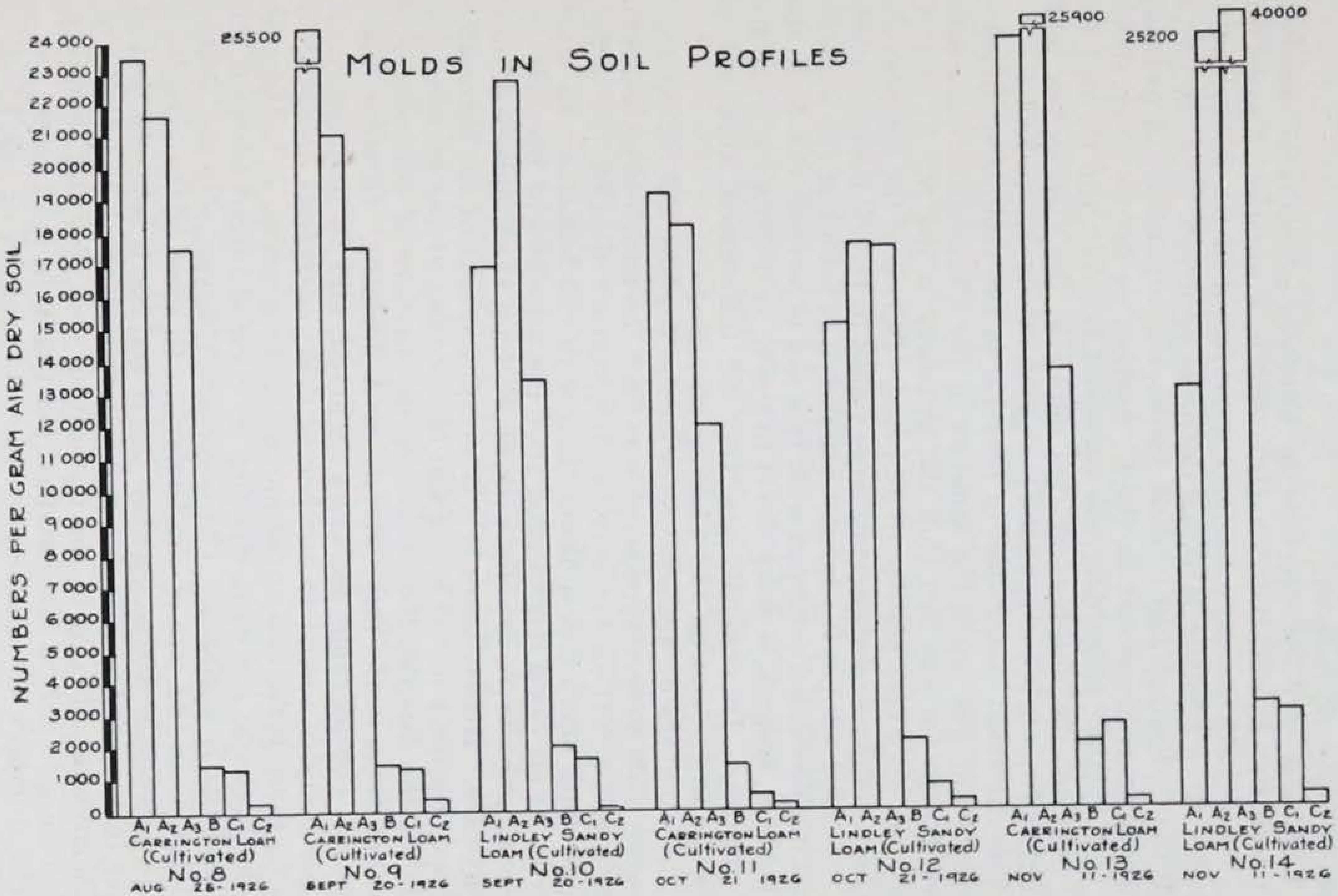

Fig. 7. Molds in soil profiles—series I. (Cont.)

isms in the Carrington loam soil occurred either in the A_1 or A_2 horizons. In practically all cases there was a considerable decrease in numbers of bacteria from the A_2 to the A_3 horizon. There were two exceptions where there were slight increases from the A_2 to the A_3 horizon.

The most striking decrease in numbers of bacteria occurred between the A_3 and the B horizon and in a number of cases less than one-tenth as many bacteria were found in the B horizon as in the A_3. Another striking decrease occurred between the B and the C_1 horizon and in most instances, only one-tenth as many organisms were present in the C_1 horizon as in the layer above. A still further large decrease occurred between the C_1 and the C_2 horizon, the numbers at this depth in the Carrington loam ranging from 2,100 organisms per gram of soil, up to 7,710.

The variation in numbers of bacteria in the samples of Lindley sandy loam was much the same as in the Carrington loam samples, except for the fact that the numbers in the A_1, A_2 and A_3 horizons were very similar in all cases. In two of the samples the largest numbers of organisms were found in the A_2 horizon, while in the third sample the largest number was found at the surface. Striking decreases occurred with this soil type from the A_3 to the B horizon, and again from the B to the C_1 and from the C_1 to the C_2 horizon. In general, however, the differences were not so large as in the case of the Carrington loam.

The numbers of actinomycetes in the surface soil of the Carrington loam were very much lower than the numbers of bacteria. Decreases occurred, however, at the various depths, the differences being much less striking than with the bacteria. In other words, in all cases it appeared that the numbers of bacteria decreased much more rapidly with depth than the numbers of actinomycetes. Hence, there is a larger proportion of the actinomycetes to bacteria in the lower soil layers than at the surface. In some of the samples the difference in numbers of actinomycetes was not great in the three surface or A horizons. In other cases, however, considerable decreases occurred, and in practically all of the samples a smaller number of these organisms occurred in the A_3 than in the two upper horizons. In general, as in the case of the bacteria, the most striking decrease occurred between the A_3 and the B horizons. The decrease, however, was not nearly so large as in the case of the bacteria. In some of the samples a large decrease occurred between the B and the C horizons, but in other instances the differences were not so great. The number of actinomycetes present in the C_2 horizon was very low, however, amounting to only a few hundred per gram, in most cases.

The numbers of actinomycetes in the samples of the Lindley sandy loam were very similar to those present in the Carrington loam, the largest number occurring either in the A_1 horizon or in the A_2 horizon. There was a decrease in every case to the A_3 horizon. As in the case of the Carrington loam, large decreases appeared between the A_3 and the B horizons, the most striking drop in numbers occurring between these depths. Large decreases also occurred from the B to the C horizon and in the C_2 horizon again only a few hundred actinomycetes were found per gram of soil.

The numbers of molds present in the various samples of the Carrington loam were very small in comparison with the numbers of bacteria and actinomycetes per gram of soil. Considerable decreases in the numbers occurred, however, and in the C_2 horizon only a few usually were present. As with the bacteria and the actinomycetes, the largest decrease appeared between the A_3 and the B horizons in practically all cases. The decreases between the B and C horizons was not nearly so pronounced in the case of the molds. Usually the decreases from the A_1 to the A_2 and A_3 horizons were small, and in one instance the largest numbers of molds appeared in the A_2 horizon. In all other cases, however, the largest numbers were present in the surface or A_1 horizon. The decreases in the numbers of molds were not nearly so great in proportion to the total numbers present, as in the case of the actinomycetes or the bacteria. Hence, it appears that in the lower depths, there is a narrower ratio between the molds and bacteria and also between the molds and actinomycetes than in the surface layers.

In the Lindley sandy loam the numbers of molds were very similar to those secured in the Carrington loam samples and the decreases were likewise similar. In all three samples, however, the largest numbers of molds occurred in the A_2 or A_3 horizon rather than in the surface or A_1 horizon. The greatest decrease occurred from the A_3 to the B horizon. Further decreases occurred at lower depths, but were not so pronounced, the lowest numbers of molds occurring in all cases in the C_2 horizon.

MOISTURE

The variations in the moisture content of the different layers of the soil types sampled on the various dates thru 1926 show no relationship to the content of bacteria, actinomycetes or molds. In all cases the moisture increased from the A_1 to the A_2 horizons and this in the majority of cases was accompanied by an increase in numbers of bacteria. In some cases the numbers of actinomycetes and molds also increased. In a few cases the numbers of bacteria decreased from the A_1 to the A_2 horizon altho there was an increased moisture content. In many of the samples, increases in moisture occurred from the A_2 to the A_3 horizon, and these were accompanied in practically all cases by decreases in numbers of bacteria. In some cases the decreases were not very large, but in other instances pronounced decreases occurred.

The differences were small in the moisture content of the soils in the A_3 and the B horizons in the various samples, slight increases occurring in some instances in the B horizon, and in other cases there were definite decreases. In all the samples the numbers of bacteria, actinomycetes and molds decreased to a very large extent from the A_3 to the B horizon. There is certainly no evidence of any moisture effect in this decrease. Similarly in the case of the C_1 and C_2 horizons, small decreases in moisture sometimes occurred, but in other instances slight increases were noted. In all cases, however, large decreases in numbers of bacteria, actinomycetes and molds were found in the C_1 and C_2 horizons. Again there is no evidence of a moisture relationship.

While in some instances certain relationships between the moisture content of the soil and the content of bacteria, actinomycetes and molds may be noted, in general the numbers of these organisms decreased from the surface to the lower depth without regard to moisture differences. In one or two instances the larger numbers of organisms in the surface soils in the case of the Carrington loam seem to be correlated with a higher moisture content, but in general the numbers, even in the surface layers of the same types, varied without regard to the differences in moisture conditions. It may safely be said that moisture differences are of little significance in relationship to the numbers of microorganisms in the lower soil layers and apparently have no great influence, at least within certain limits, such as prevailed in this work, upon the number of microorganisms in the surface soil. Extremes of moisture conditions would undoubtedly have a pronounced effect on the numbers of microorganisms. From the data given in this work, however, it appears that other factors may be of more significance, under more or less normal conditions.

SEASON

Since typical samples of Carrington loam were studied from June to November, and all were taken from cultivated areas, the results of the microbiological studies might be expected to indicate certain seasonal differences. The results did show some seasonal effects. Thus the largest numbers of bacteria in the surface layer of the cultivated Carrington loam were found at the first sampling on June 20, and a second maximum occurred at the last sampling on Nov. 11. The minimum number was found on Aug. 25. The numbers fluctuated some at the samplings between these extremes, but the variations were not very great. The most striking differences occurred from the first to the second sampling and from the third to the fourth sampling. The most striking increase occurred from the ninth to the tenth or last sampling. The differences in numbers of bacteria as brought about by seasonal conditions seemed to persist thruout the three surface horizons, or down to the B horizon, smaller numbers occurring in the A_3 horizon at the Aug. 25 sampling and larger numbers at the first and last samplings. In the B and C horizons, however, the seasonal effects were negligible. In fact no relationships were apparent.

Variations in seasonal conditions seemed to affect the numbers of bacteria in the Carrington loam, the largest numbers occurring in the surface layers in the A_1, A_2 and A_3 horizons in the spring and in the fall. The smallest numbers occurred in the three surface horizons in August. These results confirm earlier observations, which pointed out the fact that there were two maxima in the year for numbers of bacteria in the soil.

No conclusions are possible regarding the seasonal effect on the organisms in the Lindley sandy loam inasmuch as this soil was sampled only in the fall.

There were, likewise, little evidences of seasonal effects on the numbers of actinomycetes and molds in the soil, altho in the case of the actinomycetes there did seem to be two maxima, one in the early part of the season and the other later in the season. The maximum numbers of actinomycetes occurred in the surface soil on June 25 and in the A_2 horizon of the Carrington loam on July 23. The second maximum occurred in this soil on Nov. 11. Two minima were found on Aug. 25 and Oct. 21. No relationships were apparent in the case of the mold counts, altho larger numbers might be expected on those dates when smaller numbers of bacteria and actinomycetes occurred. There were some indications that smaller numbers of molds actually occurred when the highest numbers of bacteria were present, and vice versa, but in general the results are not definite enough to permit of conclusions.

CULTIVATION

The effect of cultivation of the soil on the numbers of microorganisms is indicated by a comparison of the results secured on the cultivated Carrington loam on June 20 (No. 1), and on the virgin Carrington loam on the same date (No. 2). The numbers of bacteria were very much greater in the surface or A_1 horizon of the cultivated soil, larger in the A_2 horizon and slightly greater in the A_3 horizon. In the virgin Carrington a greater number of bacteria was in the B horizon than in the culvitated Carrington. The numbers in the C horizon were similar.

In the case of the actinomycetes the numbers were much greater in the cultivated Carrington, and the larger numbers continued thru the A_2 and the A_3 horizons. Only slight differences occurred in the case of the B and C horizons. With the molds there was a larger number in the three surface horizons and, as in the case of the bacteria, a larger number in the B horizon in the virgin Carrington than in the cultivated Carrington. No differences were apparent in the C horizon.

The data serve to indicate the fact that cultivation increases the number of microorganisms in the surface soil to a considerable extent, and the difference may extend down thru the A_3 horizon. Not only are the numbers of bacteria increased, but there are greater numbers of actinomycetes and greater numbers of molds. The increases are probably due mainly to the better food conditions which are brought about as a result of cultivation and also to the better aeration. Below the surface horizons, however, the numbers of organisms may even be somewhat greater in a virgin soil than in a cultivated soil. This seems to be especially true in this experiment in the case of the B horizon, but might not always occur. It would seem from these results that the largest differences in numbers of microorganisms due to cultivation occur in the surface layers.

SOIL TYPES

The relationship of the soil type to content of microorganisms is indicated by a comparison of the results secured on the Carrington loam and the Lindley sandy loam on the three later dates of sampling. On Sept. 20 the Carrington loam seemed to contain the largest number of organisms in the surface soil, but on Oct. 21 and Nov. 11, the Lindley sandy loam contained slightly greater numbers. There were variations at the different depths, but, in general, no distinct difference between the two soil types was evidenced. The Lindley sandy loam is slightly lighter in color at the surface than the Carrington loam and contains a sufficiently larger quantity of sand to be classified as a sandy loam. It might be expected, therefore, that the numbers of microorganisms would be somewhat greater in the Carrington loam than in the Lindley, due to its darker color and somewhat heavier texture. This does not seem to be the case, however, and apparently other factors are of more significance than the slight differences in color and texture which occur in the case of these two types. In general it may be said that there is no evidence of type effect nor of any definite influence from the slight differences in color and texture in the case of the two soils studied in this particular series.

SERIES II.

In 1927, the Carrington loam, the Clyde silty clay loam and the Dickinson fine sandy loam were sampled on April 25, May 4, May 15, May 29 and June 18, typical profiles being selected in all cases. Pits were dug in each type and samples drawn as in the previous season. The numbers of bacteria, actinomycetes and molds were determined by the methods previously employed. Careful descriptions of all the soils were made as follows:

Carrington Loam, No. 15

A_1 (0-2")—Dark grayish-brown loam, granular in structure.

A_2 (2-6")—Dark grayish-brown loam, containing considerable silt. Granular in structure.

A_3 (6-18")—Dark grayish-brown loam, granular.

B (18-24")—Dark brown silty clay loam. Organic infiltrations occur. Structureless. Transition zone.

C_1 (24-31")—Yellowish-brown silty clay loam to silty clay, containing some coarse sand and fine sand and occasional bits of gravel. Structureless.

C_2 (31-50")—Yellowish-brown silty clay loam to silty clay, containing a higher percentage of coarse sand and grit than the layer above. Lighter in color than horizon above.

Clyde Silty Clay Loam, No. 16

A_1 (0-2")—Black or almost black sticky silty clay loam. No definite structure.

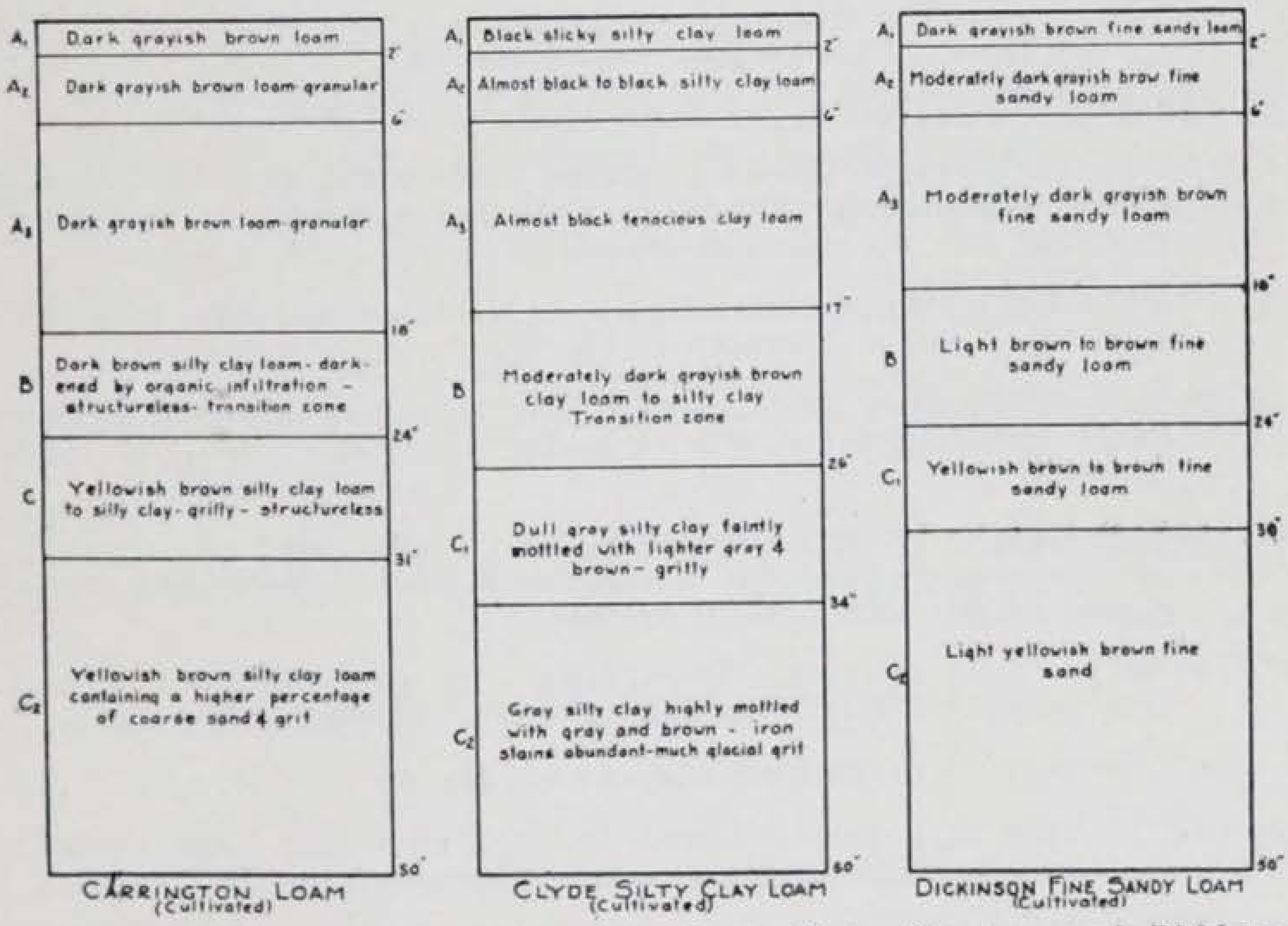

Fig. 8. Typical profiles of Carrington loam, Clyde silty loam and Dickinson fine sandy loam.

A_2 (2-6")—Almost black to black silty clay loam.

A_3 (6-17")—Almost black tenacious clay loam.

B (17-26")—Moderately dark grayish-brown clay loam to silty clay, stained with organic infiltrations. Transition zone.

C_1 (26-34")—Dull gray silty clay, mottled faintly with lighter gray and brown and a few iron stains. Considerable glacial grit present, mostly coarse sand and fine sand.

C_2 (34-50")—Gray silty clay highly mottled with gray and brown. Iron stains abundant. Contains much grit. Very heavy and plastic. Lighter in color than layer above.

Dickinson Fine Sandy Loam, No. 17

A_1 (0-2")—Moderately dark grayish-brown fine sandy loam. Single grain structure.

A_2 (2-6")—Moderately dark grayish-brown fine sandy loam, similar to layer above.

A_3 (6-16")—Fine sandy loam, similar to layers above except slightly lighter in color. Uniform texture.

B_1 (16-24")—Transition zone, but not definite. Light brown to brown fine sandy loam, darkened slightly by organic infiltrations.

B_2 (24-30")—Yellowish-brown to brown fine sandy loam, uniform in texture.

C (30-50")—Light yellowish-brown fine sand becoming slightly coarser with depth.

Carrington Loam, No. 18

A_1 (0-2")—Dark grayish-brown loam, finely granular.

A_2 (2-6")—Dark grayish-brown to almost black loam, very high in silt. Finely granular in structure. Contains a minimum amount of fine sand and no coarse material.

A_3 (6-20")—Dark grayish-brown to almost black mellow loam, very high in silt and clay. Granular.

B (20-25")—Transition zone. Brown silty clay loam colored with organic infiltrations to almost a dark brown. Color not solid. Granular.

C_1 (25-36")—Light yellowish-brown or light brown silty clay, containing some coarse sand, but mostly fine sand, and rarely any glacial gravel. Color solid. Structureless.

C_2 (36-50")—Light yellowish-brown silty clay containing much grit, principally fine sand. Occasional bits of glacial gravel occur.

Clyde Silty Clay Loam, No. 19

A_1 (0-2")—Very dark grayish-brown to black silty clay loam, containing many particles of coarse sand. Coarsely granular.

A_2 (2-6")—Black silty clay loam, containing a few coarse particles. Structureless.

A_3 (6-14")—Black silty clay loam containing some coarse sand, slightly heavier than layer above. Increases in heaviness with depth.

B (14-20")—Dark grayish-brown clay loam to silty clay, slightly lighter in color than the layer above.

C_1 (20-28")—Transition zone. Grayish-brown silty clay containing some coarse sand. Faintly mottled with gray and shows a few iron stains. Structureless.

C_2 (28-50")—Grayish-brown silty clay or clay with a few gray and yellowish-brown mottlings. Frequent iron stains present. Structureless.

Dickinson Fine Sandy Loam, No. 20

A_1 (0-2")—Moderately dark grayish-brown fine sandy loam, single grain structure.

A_2 (2-6")—Moderately dark grayish-brown fine sandy loam, uniform in texture.

A_3 (6-18")—Dark grayish-brown fine sandy loam, somewhat lighter in color than layer above.

B_1 (18-25")—Grayish-brown or brown fine sandy loam, stained with organic infiltrations. Color not solid. Transition zone.

B_2 (25-35")—Brown to yellowish-brown fine sandy loam, uniform in color and texture.

C (35-50")—Light yellowish-brown fine sandy loam or fine sand uniform in color and texture.

Carrington Loam, No. 21

A_1 (0-2")—Dark grayish-brown friable loam, granular in structure.

A_2 (2-6")—Very dark grayish-brown friable loam, granular.

A_3 (6-18")—Very dark grayish-brown heavy but friable loam, containing a very high percentage of silt.

B (18-25")—Transition zone. Dark brown silty clay loam, highly colored with organic infiltrations.

C_1 (25-30")—Yellowish-brown silty clay, containing a moderate amount of grit, with much fine sand. No coarse material. A few faint iron stains present.

C_2 (30-50")—Yellowish-brown silty clay, faintly mottled with gray, especially in the lower depths. Plastic. Occasional iron stains. No pebbles nor rock fragments present. Fine sand predominates.

Dickinson Fine Sandy Loam, No. 22

A_1 (0-2")—Moderately dark grayish-brown uniform fine sandy loam or sandy loam. Single grain structure.

A_2 (2-6")—Dark grayish-brown fine sandy loam. Single grain structure.

A_3 (6-22")—Dark grayish-brown fine sandy loam, slightly lighter in color than layer above.

B_1 (22-27")—Transition zone. Brown fine sandy loam or loamy fine sand, stained with organic infiltrations. An almost solid color.

B_2 (27-37")—Light brown uniform loamy fine sand. No coarse pebbles, rock nor rock fragments occur.

C (37-50")—Light yellowish-brown sand, uniform in texture and color. Single grain structure.

Clyde Silty Clay Loam, No. 23

A_1 (0-2")—Very dark brown friable silty clay loam.

A_2 (2-6")—Very dark brown to black silty clay loam, containing a small amount of fine sand.

A_3 (6-16")—Very dark brown to black heavy silty clay loam to clay loam. Small amount of fine sand present.

B (16-22")—Transition zone. Dark grayish-brown plastic silty clay.

C_1 (22-34")—Gray silty clay, plastic and containing a small amount of fine sand.

C_2 (34-50")—Gray silty clay mottled faintly with brown and a few iron stains. Considerable fine and coarse sand present. Large rocks and boulders frequently found below 40 inches. Soil very tenacious and plastic.

Carrington Loam, No. 24

A_1 (0-2")—Dark grayish-brown friable loam.

A_2 (2-6")—Grayish-brown friable silt loam.

A_3 (6-20")—Dark brown silt loam, containing much silt.

B (20-28")—Transition zone. Brown silty clay loam, colored with organic infiltrations.

C_1 (28-35")—Yellowish-brown silty clay loam containing some fine grit.

C_2 (35-50")—Yellowish-brown silty clay loam with considerable fine grit and sand. More friable than layer above.

Dickinson Fine Sandy Loam, No. 25

A_1 (0-2")—Dark grayish-brown uniform fine sandy loam.

A_2 (2-6")—Dark grayish-brown fine sandy loam.

A_3 (6-14")—Grayish-brown fine sandy loam.

B_1 (14-18")—Fine sandy loam, slightly lighter in color than layer above and less loamy.

B_2 (18-29")—Brown loamy fine sand.

C (29-50")—Lighter brown or yellowish-brown sand or fine sand. Uniform texture. No coarse materials occur.

Clyde Silty Clay Loam, No. 26

A_1 (0-2")—Very dark brown silty clay loam, with some fine sand.

A_2 (2-6")—Almost black silty clay loam, very heavy and sticky.

A_3 (6-16")—Dark grayish-brown to almost black heavy silty clay loam.

B (16-24")—Transition zone. Dark grayish-brown to grayish-brown silty clay, containing a small amount of fine grit. Much organic infiltration.

C_1 (24-32")—Dull grayish silty clay, very plastic.

C_2 (32-50")—Drab or gray silty clay faintly mottled with gray and brown. Some coarse materials present; grit and fine sand occur and occasional small granite boulders.

Carrington Loam, No. 27

A_1 (0-2")—Dark grayish-brown friable loam.

A_2 (2-6")—Grayish-brown friable loam.

A_3 (6-14")—Grayish-brown loam, containing considerable fine sand.

B (14-24")—Transition zone. Dark grayish-brown to grayish-brown silty clay loam, highly colored with organic infiltrations. Color appears solid.

C_1 (24-32")—Yellowish-brown silty clay loam, containing some fine grit.

C_2 (32-50")—Yellowish-brown sticky plastic silty clay loam, faintly mottled with gray. Very little grit occurs.

Dickinson Fine Sandy Loam, No. 28

A_1 (0-2")—Moderately dark grayish-brown fine sandy loam.

A_2 (2-6")—Dark grayish-brown fine sandy loam.

A_3 (6-18")—Fine sandy loam slightly lighter in color than above.

B_1 (18-26")—Brown fine sandy loam, with some organic infiltrations. Transition zone.

B_2 (26-40")—Light brown fine sand.

C (40-50")—Pale yellowish-brown sand or fine sand. Uniform in texture.

Clyde Silty Clay Loam, No. 29

A_1 (0-2")—Dark grayish-brown to black silty clay loam.

A_2 (2-6")—Black heavy silty clay loam.

A_3 (6-21")—Very dark grayish-brown to black plastic silty clay loam to clay loam.

B (21-25")—Transition zone. Grayish-brown silty clay, faintly mottled with gray.

TABLE II. MICROORGANISMS IN SOME SOIL PROFILES IN IOWA

Soil type and date sampled	Depth soil horizon	Percent H_2O	Bacteria per gram air-dry soil	Actinomycetes per gram air-dry soil	Molds per gram air-dry soil
Carrington loam Number 15 April 25, 1927	A_1(0-2″)	22.0	5,901,000	1,020,000	5,100
	A_2(2″-6″)	22.0	4,090,000	890 000	5,100
	A_3(6″-18″)	20.0	2,500,000	620,000	7,500
	B (18″-24″)	20.0	450,000	50,000	875
	C_1(24″-31″)	18.0	94,000	7,300	480
	C_2(31″-50″)	16.0	14,200	1,190	140
Clyde silty clay loam Number 16 April 25, 1927	A_1(0-2″)	30.0	3,500,000	1,140,000	8,570
	A_2(2″-6″)	31.0	2,000,000	579,000	2,890
	A_3(6″-17″)	24.5	866,000	265,000	2,650
	B (17″-26″)	18.5	441,000	73,000	490
	C_1(26″-34″)	19.0	59,000	4,900	123
	C_2(34″-50″)	18.5	10,900	980	85
Dickinson fine sandy loam Number 17 April 25, 1927	A_1(0-2″)	10.0	1,550,000	333,000	7,770
	A_2(2″-6″)	11.0	674,000	112,000	4,490
	A_3(6″-16″)	11.0	449,000	———	5,610
	B_1(16″-24″)	12.0	250,000	45,000	454
	B_2(24″-30″)	11.5	97,000	13,500	565
	C (30″-50″)	13.0	15,860	1,140	103
Carrington loam Number 18 May 4, 1927	A_1(0-2″)	21.0	6,590,000	1,390,000	6,580
	A_2(2″-6″)	21.0	4,680,000	1,510,000	6,580
	A_3(6″-20″)	20.0	2,375,000	525,000	9,750
	B (20″-25″)	19.0	419,000	83,900	960
	C_1(25″-36″)	19.0	98,000	13,000	590
	C_2(36″-50″)	16.5	18,600	1,590	200
Clyde silty clay loam Number 19 May 4, 1927	A_1(0-2″)	25.6	5,060,000	1,340,000	12,100
	A_2(2″-6″)	26.4	1,570,000	430,000	6,100
	A_3(6″-14″)	18.8	650,000	160,000	1,600
	B (14″-20″)	15.0	529,000	100,000	449
	C_1(20″-28″)	15.5	79,000	6,500	230
	C_2(28″-50″)	15.5	13,000	1,650	120
Dickinson fine sandy loam Number 20 May 4, 1927	A_1(0-2″)	6.0	1,280,000	234,000	6,370
	A_2(2″-6″)	8.0	790,000	217,000	6,300
	A_3(6″-18″)	7.8	580,000	173,000	7,810
	B_1(18″-25″)	7.4	313,000	64,000	648
	B_2(25″-35″)	7.0	118,000	20,900	806
	C (35″-50″)	8.7	22,200	2,240	118
Carrington loam Number 21 May 15, 1927	A_1(0-2″)	15.0	4,640,000	588,000	5,880
	A_2(2″-6″)	19.0	5,180,000	980,000	11,700
	A_3(6″-18″)	20.0	1,180,000	250,000	8,750
	B (18″-25″)	19.7	608,000	120,000	590
	C_1(25″-30″)	19.3	260,000	57,000	200
	C_2(30″-50″)	19.4	53,400	1,100	170
Dickinson fine sandy loam Number 22 May 15, 1927	A_1(0-2″)	5.0	1,730,000	473,000	8,900
	A_2(2″-6″)	8.0	2,030,000	565,000	9,400
	A_3(6″-22″)	7.5	973,000	216,000	3,400
	B_1(22″-27″)	7.0	407,000	75,000	320
	B_2(27″-37″)	6.8	256,000	53,000	450
	C (37″-50″)	6.9	62,300	7,500	160
Clyde silty clay loam Number 23 May 15, 1927	A_1(0-2″)	17.5	3,870,000	606,000	6,300
	A_2(2″-6″)	26.0	6,170,000	940,000	9,400
	A_3(6″-16″)	25.7	2,970,000	560,000	13,700
	B (16″-22″)	16.5	667,000	65,800	820
	C_1(22″-34″)	15.5	421,000	35,500	370
	C_2(34″-50″)	15.5	81,600	2,300	71
Carrington loam Number 24 May 29, 1927	A_1(0-2″)	18.0	4,140,000	487,000	3,900
	A_2(2″-6″)	19.0	4,810,000	617,000	3,700
	A_3(6″-20″)	21.0	2,280,000	506,000	2,500
	B (20″-28″)	19.0	506,000	12,000	490
	C_1(28″-35″)	17.0	343,000	———	240
	C_2(35″-50″)	16.0	34,500	———	83

TABLE II—Continued

Soil type and date sampled	Depth soil horizon	Percent H_2O	Bacteria per gram air-dry soil	Actino-mycetes per gram air-dry soil	Molds per gram air-dry soil
Dickinson fine sandy loam Number 25 May 29, 1927	A_1(0-2")	9.0	1,570,000	430,000	7,600
	A_2(2"-6")	10.0	1,330,000	380,000	8,800
	A_3(6"-14")	12.0	710,000	220,000	2,800
	B_1(14"-18")	12.0	530,000	56,000	560
	B_2(18"-29")	13.0	290,000	55,000	550
	C (29"-50")	11.5	61,000	1,020	68
Clyde silty clay loam Number 26 May 29, 1927	A_1(0-2")	28.0	5,600,000	550,000	6,900
	A_2(2"-6")	30.0	6,500,000	280,000	8,500
	A_3(6"-16")	31.0	4,050,000	210,000	9,400
	B (16"-24")	26.0	610,000	81,000	405
	C_1(24"-32")	24.0	310,000	39,000	130
	C_2(32"-50")	26.0	47,000	1,300	54
Carrington loam Number 27 June 18, 1927	A_1(0-2")	20.0	5,500,000	1,100,000	7,500
	A_2(2"-6")	20.0	5,000,000	870,000	5,000
	A_3(6"-14")	22.0	3,400,000	530,000	8,400
	B (14"-24")	20.0	630,000	3,700	375
	C_1(24"-32")	16.0	220,000	——	110
	C_2(32"-50")	15.5	46,400	1,100	11
Dickinson fine sandy loam Number 28 June 18, 1927	A_1(0-2")	7.0	1,830,000	320,000	5,300
	A_2(2"-6")	9.0	2,190,000	650,000	9,200
	A_3(6"-18")	10.0	1,270,000	440,000	4,700
	B_1(18"-26")	12.0	556,000	74,000	790
	B_2(26"-40")	9.0	340,000	60,400	580
	C (40"-50")	6.0	45,700	1,200	110
Clyde silty clay loam Number 29 June 18, 1927	A_1(0-2")	22.0	6,700,000	705,000	7,800
	A_2(2"-6")	25.0	7,800,000	800,000	6,800
	A_3(6"-21")	26.0	4,400,000	470,000	2,700
	B (21"-25")	24.0	500,000	52,000	460
	C_1(25"-38")	19.0	230,000	18,000	240
	C_2(38"-50")	17.0	34,000	1,200	36

C_1 (25-38")—Drab or dull gray heavy sticky silty clay, containing much fine grit.

C_2 (38-50")—Gray silty clay mottled with gray and brown with a few iron stains.

Typical profiles of the Carrington loam, the Clyde silty clay loam and Dickinson fine sandy loam are shown in fig. 8.

Results of Microbiological Studies

The results of the microbiological studies are presented in table II, and the counts of bacteria, actinomycetes and molds are shown graphically in figs. 9 and 10 for the bacteria, in 11 and 12 for the actinomycetes and in 13 and 14 for the molds.

DEPTH

The data given in the tables and presented graphically in the figures show the very striking decreases in numbers of microorganisms from the surface down thru the C horizon, or to a depth of 50 inches. In the case of the Carrington loam, the largest number of bacteria per gram of soil was found in the A_1 horizon in three of the samples, and a decrease occurred from the A_1 to the A_2 horizon. This decrease, however, was not very great. In two of the samples a slightly larger number of bacteria was found in the A_2 horizon than at the surface. In all cases there was a large

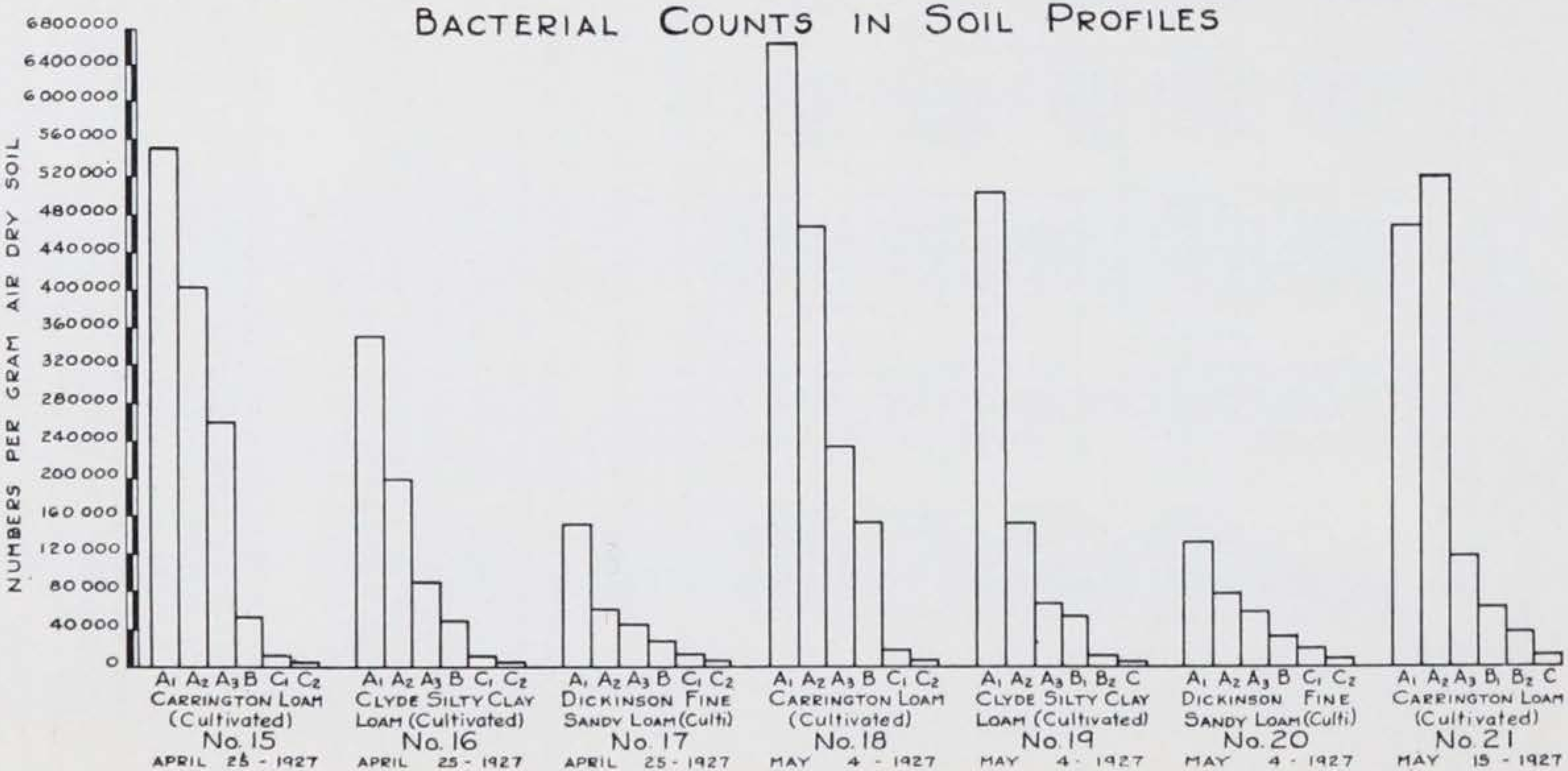

Fig. 9. Bacterial counts in soil profiles—series II.

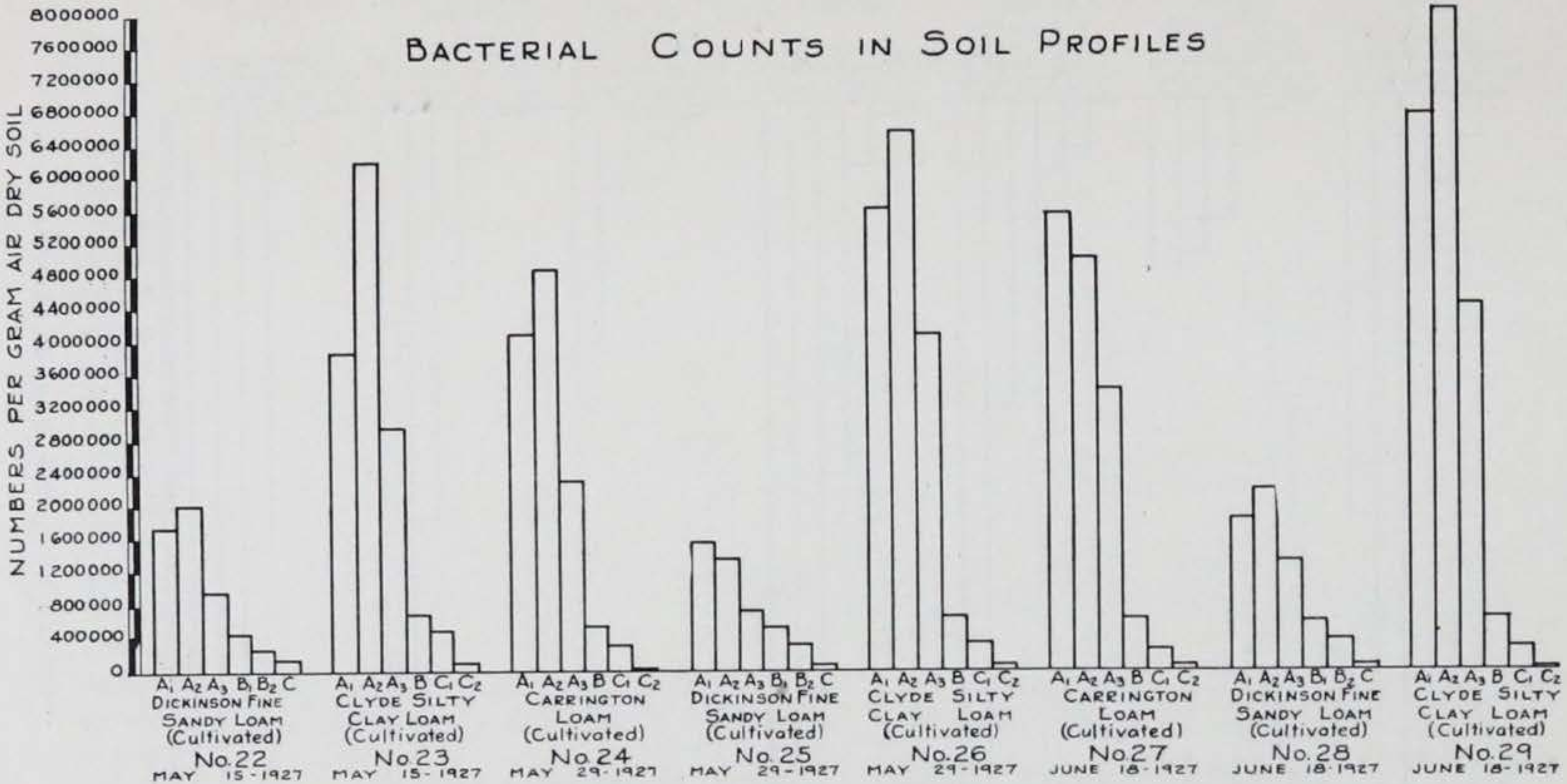

Fig. 10. Bacterial counts in soil profiles—series II. (Cont.)

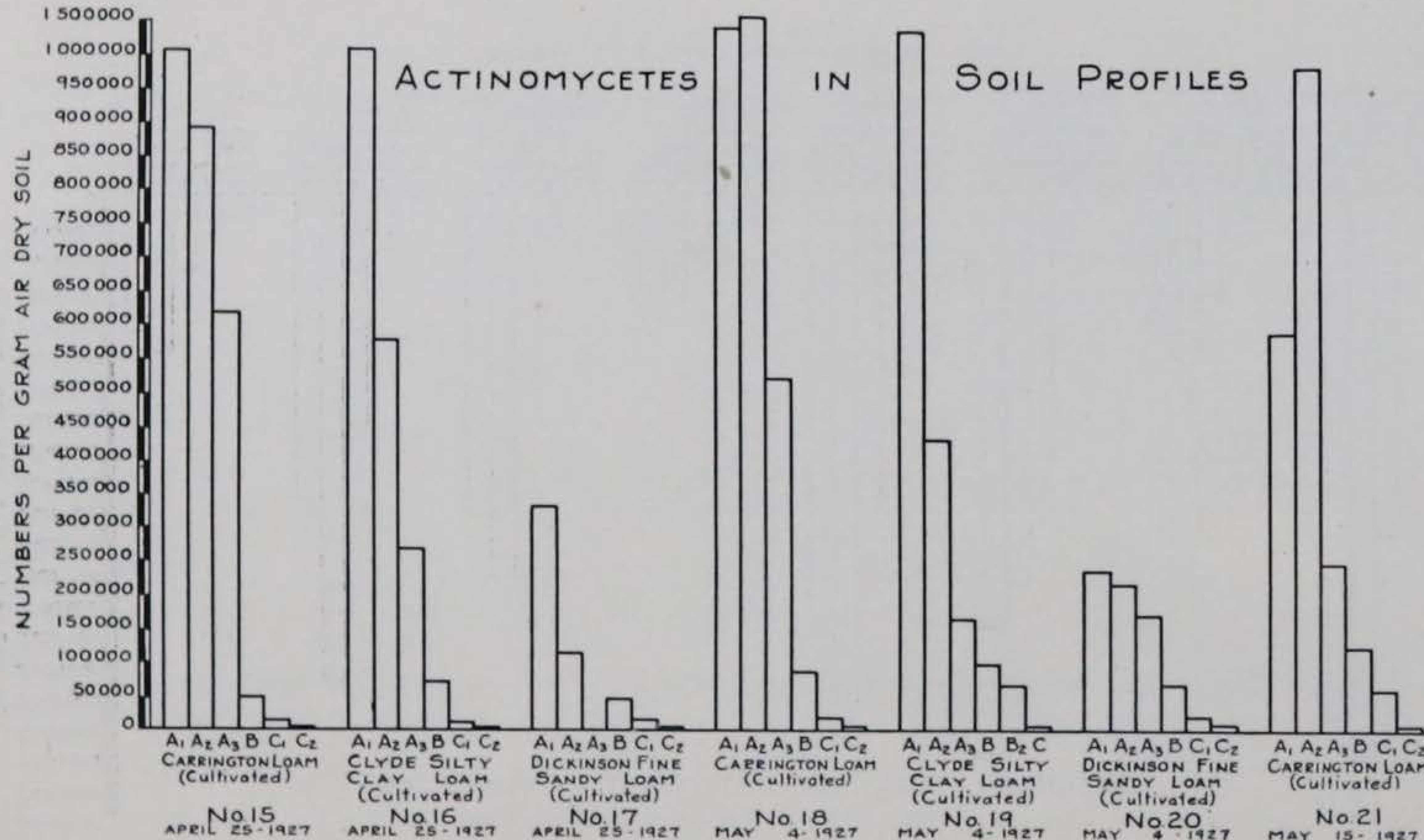

Fig. 11. Actinomycetes in soil profiles—series II.

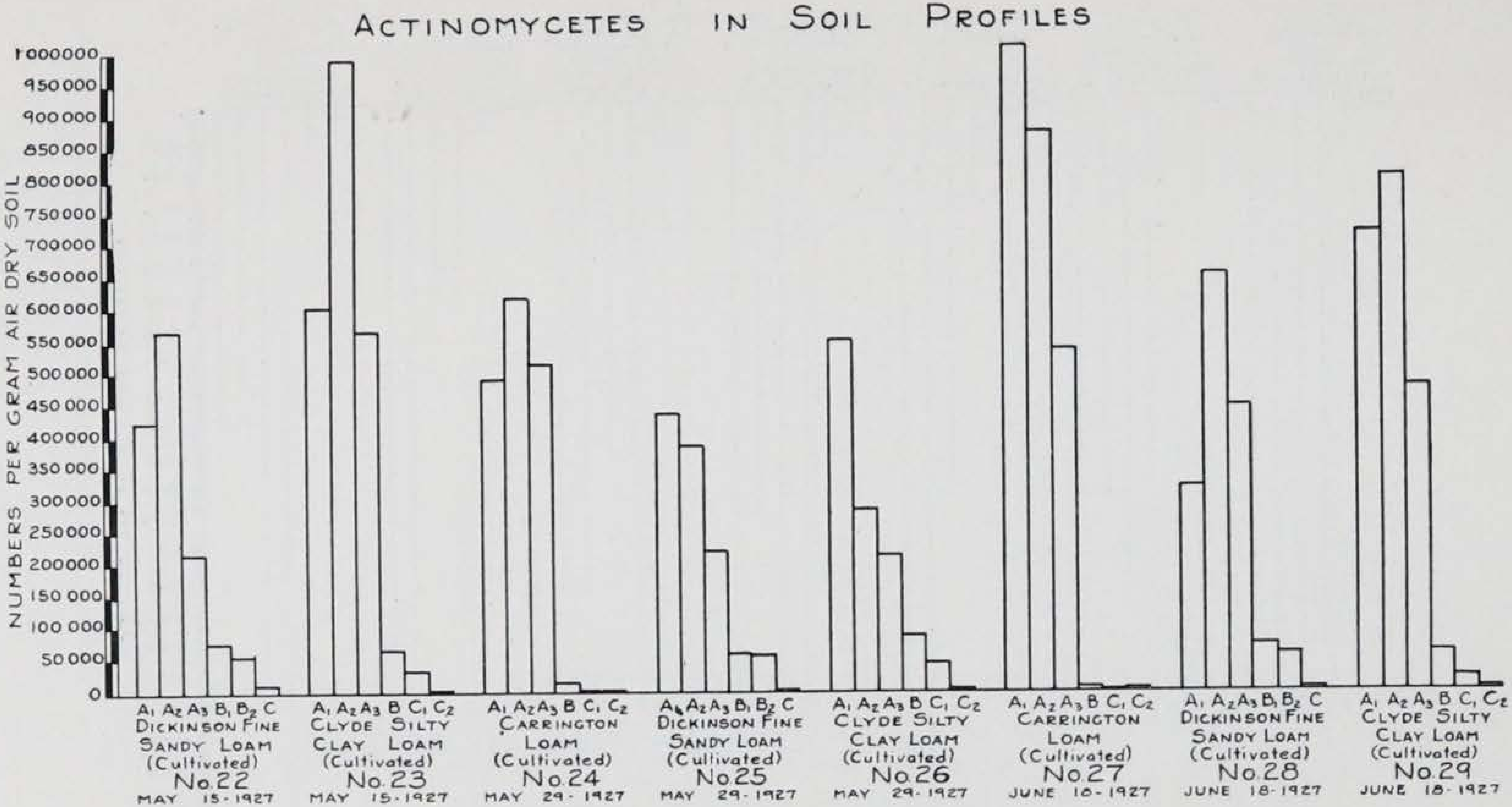

Fig. 12. Actinomycetes in soil profiles—series II. (Cont.)

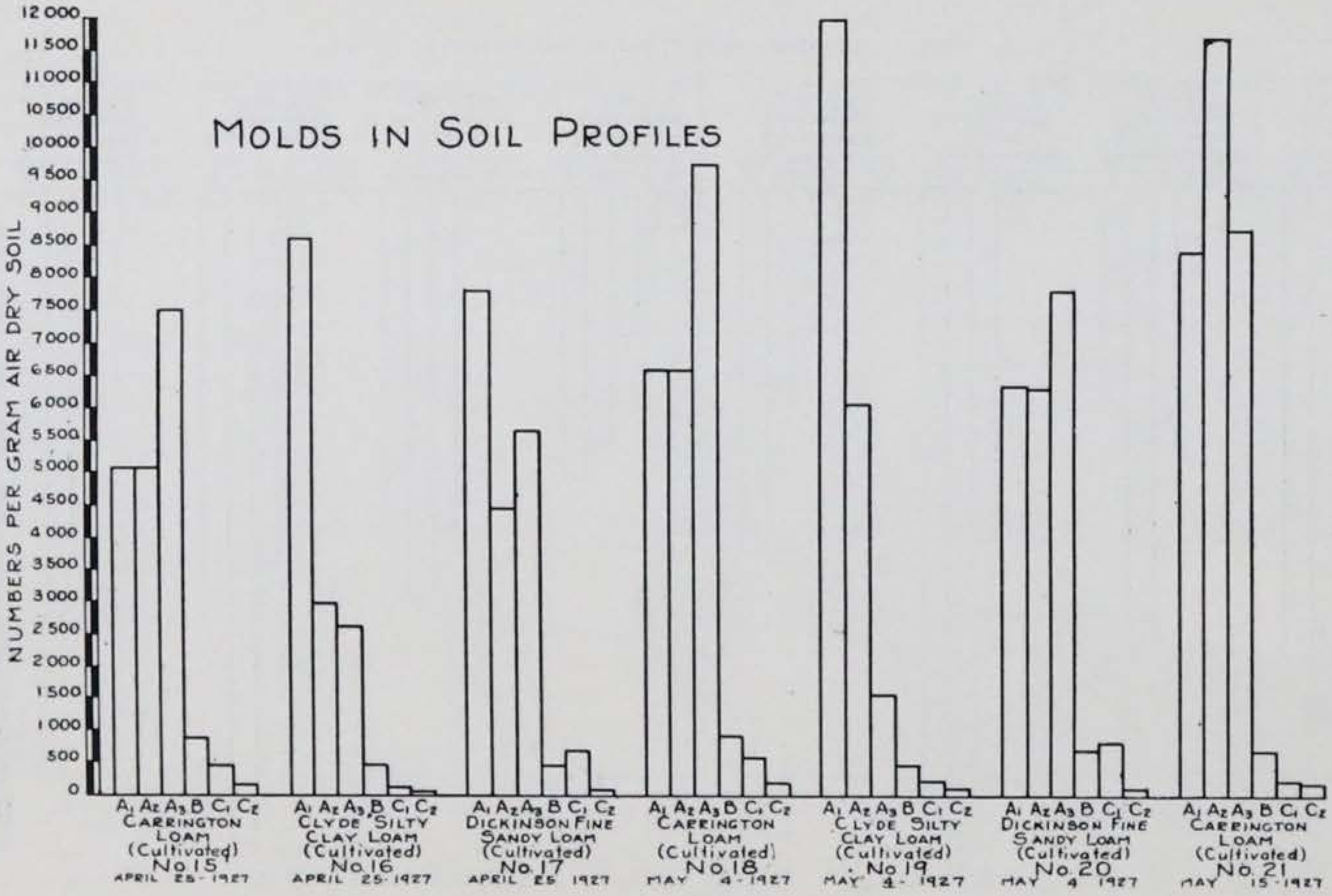

Fig. 13. Molds in soil profiles—series II.

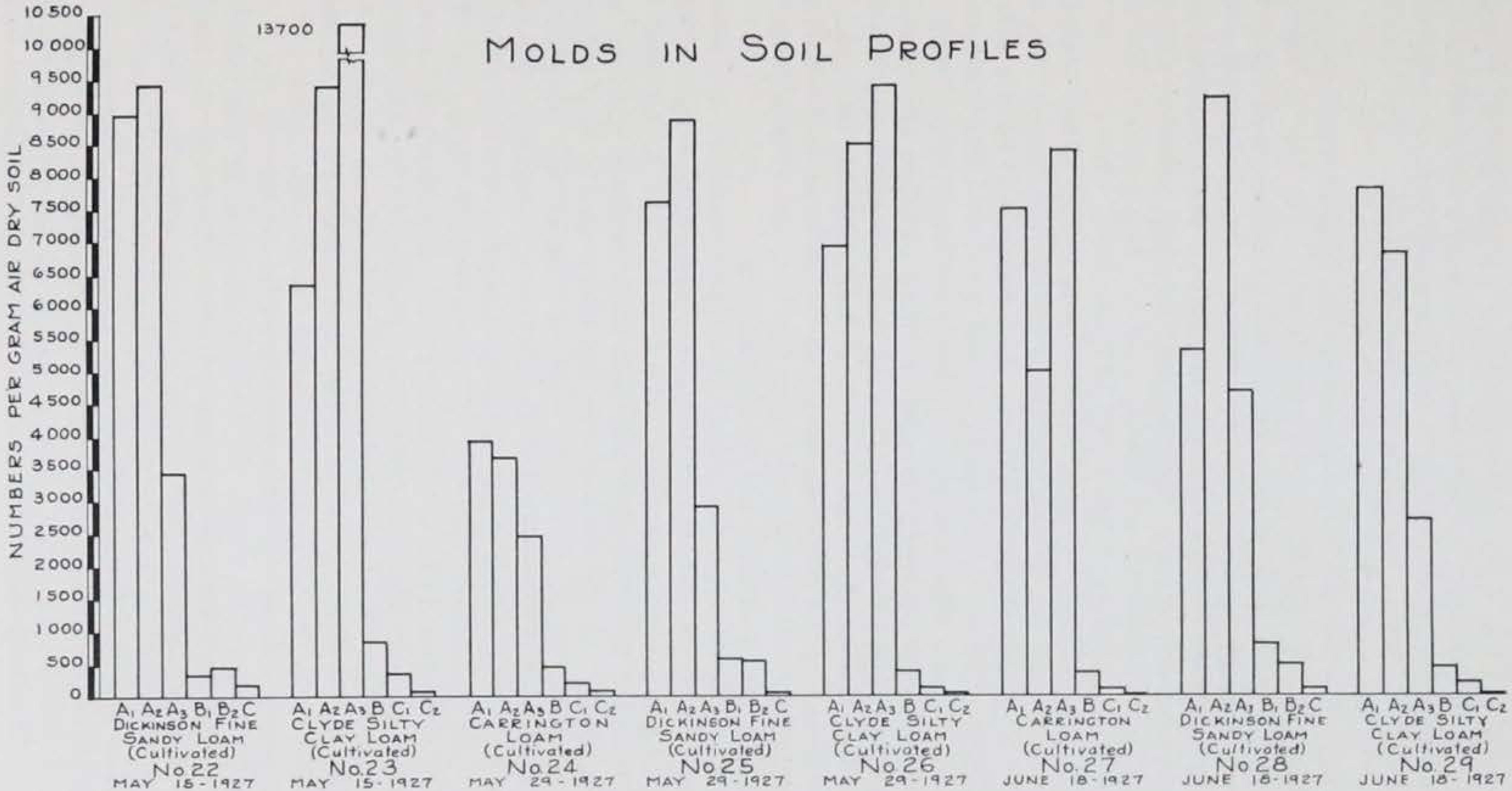

Fig. 14. Molds in soil profiles—series II. (Cont.)

decrease from the A_2 to the A_3 horizon. From the A_3 to the B horizon much the largest decrease in numbers occurred between any two depths. From the B to the C horizon a further decrease occurred, but it was not quite so large relatively. The numbers present in the C_2 horizon were rather low.

In the case of the actinomycetes the largest numbers were found in the Carrington loam either in the A_1 or the A_2 horizon. There were small differences usually in the numbers at these two depths. A large decrease occurred from the A_2 to the A_3 horizon, but in most cases the decrease was not nearly so pronounced as in the case of the bacteria. The largest decrease between any two depths was found between the A_3 and the B horizons. Further decreases occurred thru the C_1 and C_2 horizons.

With the molds the largest number was found in the Carrington loam in the A_3 horizon in three of the samplings. In one case the largest number was in the A_2 horizon and in one sample the largest number was present at the surface. The content of molds in this soil varied slightly in the three surface horizons. In general, however, a larger number seemed to occur in the lower surface layers than was the case with the bacteria and actinomycetes. The largest decrease in the number of molds occurred between the A_3 and B horizons, as noted in the case of the bacteria and actinomycetes. Decreases from the B to the C and from the C_1 to the C_2 horizon were not of significance.

With the Clyde silty clay loam, the largest numbers of bacteria appeared in the A_1 horizon in two of the samplings. In the other three cases the largest numbers were found in the A_2 horizon. In most instances the difference was not large between the two surface horizons. In the case of No. 19, there was a very unusual decrease from the A_1 to the A_2 horizon. In all the samples the depression was large from the A_2 to the A_3 horizon. This decrease was very much greater proportionately to the numbers present above than in the case of the Carrington samples. The decrease from the A_3 to the B horizon was large but not so great relatively as was the case with the samples of the Carrington loam. Likewise the decrease from the B to the C_1 horizon was pronouncd, but not so great as in the case of the Carrington loam. Decreases from the C_1 to the C_2 horizon were also noted.

The largest number of actinomycetes were present in the A_1 or the A_2 horizon of the Clyde silty clay loam, just as was noted in the case of the Carrington loam. In two instances the larger numbers were found in the A_2 horizon. In the other cases the greatest numbers occurred in the A_1 horizon. In all instances there was a large decrease from the A_2 to the A_3 horizon. As was noted in the case of the bacteria, the decrease from the A_2 to the A_3 horizon was much more pronounced with the actinomycetes in the Clyde silty clay loam than in the Carrington loam.

The decrease from the A_3 to the B horizon was pronounced, and there were also very pronounced decreases from the B to the C_1 horizon. In general, however, the largest relative decrease occurred between the A_2 and the A_3 horizons. The numbers present in the C_2 horizon of this type were very low.

With the molds the largest numbers were found in the A_1 or surface horizon of three of the samples. In two cases the largest numbers were present in the A_3 horizon. It would seem, therefore, that there may be some variation in the number of molds in this soil in the three surface layers, and in some instances the largest numbers may be present in the lowest part of the surface or A horizon. The largest decrease in numbers of molds occurred between the A_3 and B horizons as in the case of the Carrington loam. Decreases from the B to the C_1 and to the C_2 horizon were small and relatively unimportant.

The numbers of bacteria in the Dickinson fine sandy loam were the largest in the A_1 or the A_2 horizons. In three instances the greatest numbers occurred in the A_1 horizon. In the other two samples the largest numbers were found in the A_2 horizons. The differences, however, were not very pronounced in these cases.

There was a large decrease from the A_2 to the A_3 horizon in all of the samples. A further decrease from the A_3 to the B_1 horizon was noted, but in most instances this decrease was not relatively so large. A decrease from the B_1 to the B_2 horizon was noted in all the samples, but this decrease too was not pronounced. A large decrease occurred between the B_2 and the C horizons.

With the actinomycetes the largest numbers were found either in the A_1 or the A_2 horizon, in some cases the A_1 horizon showing slightly greater numbers, while in other instances the A_2 horizon was the highest in numbers of these organisms. Decreases occurred from the A_2 to the A_3 horizon in all instances. These, however, were not relatively large. Large decreases occurred between the A_3 and the B_1 horizons. Generally the largest decrease was found between these two horizons. Small decreases occurred between the B_1 and the B_2 horizons. A further decrease, which was rather pronounced, occurred between the B_2 and the C horizons.

With the molds, the largest numbers in the Dickinson fine sandy loam occurred irregularly in the A_1, the A_2 or the A_3 horizons. In one instance the largest numbers were found in the A_3 horizon. In the majority of cases the largest numbers occurred in the A_2 horizon. The most striking decreases were found from the A_3 to the B_1 horizon. Decreases from the B_1 to the B_2 horizon and from the B_2 to the C horizon were small and relatively unimportant.

It appears from these data that the decreases are large in the numbers of the various groups of microorganisms from the surface to the lower soil layers of the three soil types studied. The numbers dropped from several million bacteria per gram of soil in the surface horizon, to a few thousand per gram in the C horizon. A few thousand actinomycetes were found at these lower depths, and only a very few molds occurred. The numbers of molds were relatively low, amounting to only a few thousand per gram of soil in comparison with several hundred thousand to over a million actinomycetes and to several million bacteria per gram of soil.

At the lowest depths studied, 50 inches, there were variations in numbers of microorganisms in the case of the different soil types, but the differences were not nearly so great at the lower depths as at the surface. Usually the greatest decrease in numbers of bacteria occurred between the A_3 and the B horizons. Large decreases also occurred from the B to the C horizons. Similarly in the case of the actinomycetes, the largest decrease occurred between the A_3 and B horizons in two of the soils. In the Clyde silty clay loam, however, the largest decrease was usually found between the A_2 and the A_3 horizons, or even between the A_1 and the A_2 horizons. The number of actinomycetes in this type dropped much more rapidly than in the other soils. In the case of the molds the largest decrease occurred between the A_3 and B horizons. Below that point, there were very minor differences in numbers of molds. The largest numbers of molds in many cases occurred in the lower part of the surface layer, the A_3 horizon. In the case of bacteria and actinomycetes, however, the largest numbers were always found either in the A_1 or A_2 horizon. In most instances the relationship between the numbers of bacteria and the numbers of molds was very much narrower in the lower soil layers than at the surface. The numbers of bacteria and actinomycetes usually decreased very much more rapidly than did the molds.

MOISTURE

The variations in the moisture content of the various layers of the soils studied were without definite relation to the numbers of bacteria, actinomycetes and molds. In several instances the moisture content decreased from the surface soil to the lower layers, and the numbers of the various groups of microorganisms also decreased. In other instances, however, very slight differences, or even no differences, in the moisture conditions occurred between various layers in the soils, while large differences in the numbers of bacteria, actinomycetes and molds were found. In a considerable number of instances there were decreases in numbers of the various groups of microorganisms, while increases in moisture occurred between the same soil layers. It seems apparent, therefore, that the numbers of microorganisms decrease in the various soil types from layer to layer without regard to the variations in moisture. Probably in cases of extreme differences in moisture conditions, there might be some relationship to the numbers of microorganisms in the different layers, but in the soils studied the moisture conditions were not extreme either in the direction of high content or low content.

When the moisture content and the numbers of bacteria in the surface or A_1 horizons of the various soil types are compared, some evidence of a moisture relationship appears. The Dickinson fine sandy loam in every case showed a very much lower percentage of moisture in the A_1 horizon than the Carrington loam or the Clyde silty clay loam, and the numbers of microorganisms in that surface layer were in all cases very much lower. The same conditions pertain to the A_2 and A_3 horizons. In the B and C horizons, however, the numbers were sometimes higher in the Dickinson fine sandy loam than in the other soil types, while the moisture content was ordinarily lower. The Dickinson fine sandy loam, however, varies to such a large extent in general characteristics in the surface layer from the Carrington loam and the Clyde silty clay loam that the difference in numbers of bacteria and the lower content also of actinomycetes are probably due to other factors, as well as to the difference in moisture content. The most that can be said in this connection is that the lower moisture content of the Dickinson fine sandy loam, along with other factors, led to a lower content of bacteria and actinomycetes in the surface layer when compared with the Carrington loam and the Clyde silty clay loam.

SEASON

The soils studied in this series were sampled only in the three spring months, April, May and June, and, hence, no definite indications of seasonal relationships are apparent. There were some fluctuations, however, at the different samplings. In the Carrington loam there was a decrease from the sampling on April 25 to the sampling on May 29, which was followed by an increase and the maximum count in the surface soil was obtained for this soil on June 18. In the case of the Clyde silty clay loam, a decrease occurred from the first sampling, but the minimum numbers were secured at the sampling on May 15. This was followed by an increase and the largest number of organisms in this soil type was found in this surface layer on June 18. Variations in numbers of bacteria in the surface soil of the Dickinson fine sandy loam were hardly large enough to be significant. There was a decrease on May 4, which was followed by an increase on May 15, a decrease on May 29 and an increase on June 18.

The numbers of actinomycetes varied in much the same way as the numbers of bacteria, the lowest count being obtained in the surface layers of the Carrington loam and the Clyde silty clay loam at the sampling on May 15. The lowest numbers for the Dickinson fine sandy loam occurred on May 4. While definite conclusions cannot be drawn regarding seasonal effects, it seems that seasonal variations occur in numbers of microorganisms in the different soil types, depending upon the particular conditions.

SOIL TYPE

The three soil types compared in this series were quite different in general characteristics, and these differences are reflected to a certain extent in the numbers of bacteria and actinomycetes present in the surface soil. There are indications that the differences in texture and color of the various soils are significant. Thus the Dickinson fine sandy loam, which is lighter in color than the Carrington loam and the Clyde silty clay loam, was lower in numbers of bacteria and in numbers of actinomycetes in the surface layers. The Dickinson fine sandy loam is also much more sandy in texture than the other two types, which would also undoubtedly tend to reduce the numbers of microorganisms. The Clyde silty clay loam is heavier in texture than the Carrington loam and the numbers of microorganisms were usually lower in the surface layer. Exceptions to this, however, were found particularly in the case of the samples taken on June 18 when the numbers present in the Clyde silty clay loam were higher than those present in the Carrington loam. The Clyde silty clay loam is blacker in color than the Carrington loam and might be expected, therefore, to be higher in numbers of microorganisms. It is heavier in texture, however, and aeration is undoubtedly poorer, hence, the numbers were actually sometimes lower. The heavier texture of the Clyde silty clay loam may tend to increase the numbers of microorganisms in some instances, but in general it would reduce the numbers of microorganisms because of interference with aeration conditions. The variations in counts obtained for these two types, must, therefore, be considered to reflect the influence of all the characterisics of the soil types, some of which normally operate to increase miscroorganisms, while others cause a decrease in numbers. It is quite possible that these different factors may operate differently at various times during the seasons, depending upon climatic and seasonal conditions. Late in the spring, the numbers of bacteria and actinomycetes seemed to be somewhat greater in the Clyde silty clay loam than in the Carrington loam, which may be due to the later warming up of this soil. It is naturally a later, colder soil and it is quite possible that the temperature differences would be of considerable significance. Variations in moisture will not explain the differences in the bacterial content of these two soil types. Apparently, therefore, it is some other factor or group of factors, and probably temperature is important.

The differences in the subsoil conditions in the various types do not seem to be of large significance in connection with a determination of the numbers of bacteria and actinomycetes present in the lower layer. The Dickinson fine sandy loam, which is much coarser in texture in the subsoil and substratum, contained quite as large numbers of bacteria and actinomycetes in the lower soil layers, and in some cases showed even a higher content in the lowest horizons studied. The Clyde silty clay loam is particularly impervious in the lower soil layers, probably more so in general than the Carrington loam. There were no definite differences in the content of microorganisms in the lower horizons of these two types. With the Dickinson fine sandy loam it might be expected that there would be a lower content of microorganisms at the lower depths because of the lower plant food content and a more open, porous condition. The microorganisms, however, may be carried down from the surface in greater numbers because of the greater percolation of water in the coarse-textured Dickinson soil. Then, too, the aeration is better in the subsoil of the Dickinson fine sandy loam. In the Clyde silty clay loam and the Carrington loam subsoils, probably the chief reasons for the lower content of microorganisms, at least for the fact that there is no higher content of microorganisms, is the lack of aeration and the impervious nature of the subsoil material.

SERIES III

In the third series of tests the numbers of microorganisms were counted in samples of typical Marshall silt loam and Knox silt loam taken from profiles in Crawford County. Samples were drawn from these soils on July 29, Aug. 28, Sept. 23, Oct. 12 and Nov. 23, 1927, pits being dug and the samples taken from the various profiles as in the other series. The counts of bacteria, actinomycetes and molds were made according to the same technique followed in the earlier tests.

The profiles were carefully described, as in the case of the other soil types, and the descriptions are given below. Typical profiles of the Marshall silt loam and the Knox silt loam are shown graphically in fig. 15.

Marshall Silt Loam, No. 30

A_1 (0-2")—Dark brown smooth silt loam, finely granular.

A_2 (2-6")—Dark brown smooth silt loam, finely granular.

A_3 (6-12")—Dark brown smooth silt loam, granular, uniform in color and texture.

B_1 (12-20")—Brown to dark brown heavy silt loam highly stained with organic infiltrations. Transition zone. Finely granular structure, compact but friable.

B_2 (20-35")—Light yellowish-brown silty clay loam, finely granular, a few faint gray mottlings and rusty brown iron stains.

C (35-50")—Light yellowish-brown silty clay loam, slightly lighter in color than above and more friable. Often a pale yellow in color. Texture smooth and floury. Iron stains fairly numerous. No definite structure. Highly calcareous.

Knox Silt Loam, No. 31

A_1 (0-2")—Grayish-brown or brown silt loam.

A_2 (2-6")—Grayish-brown or brown silt loam, thin dark thread-like streaks present, from organic matter.

A_3 (6-16")—Light yellowish-brown smooth silt loam, faint granular structure. Thread-like streaks of dark colored organic matter occur; color almost solid. Calcareous.

B (16-30")—Pale yellowish floury silt loam, a few faint grayish streaks or mottlings. Highly calcareous. No granulation.

C (30-50")—Pale yellowish floury silt loam, occasional light gray lines, thin streaks or splotches, more floury than layer above. Highly calcareous. No granulation.

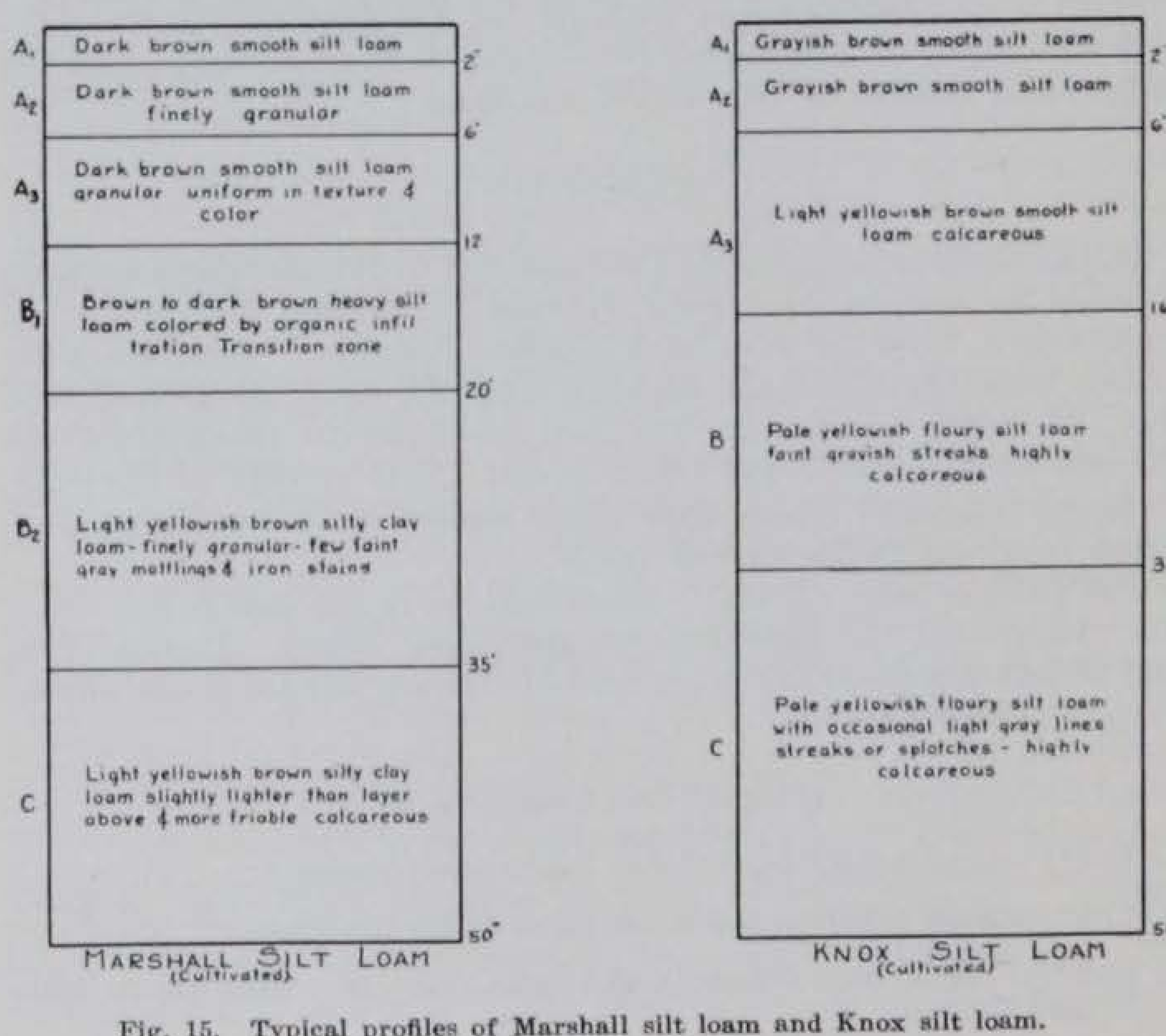

Fig. 15. Typical profiles of Marshall silt loam and Knox silt loam.

Marshall Silt Loam, No. 32

A_1 (0-2")—Dark grayish-brown silt loam.

A_2 (2-6")—Dark grayish-brown silt loam, finely granular, friable and smooth.

A_3 (6-16")—Dark grayish-brown silt loam, finely granular, friable and smooth.

B (16-26")—Brown heavy silt loam stained with organic infiltrations. Transition zone. Granular structure.

C (26-50")—Light yellowish-brown silty clay loam. Color solid. Slight granulation in the upper part of the layer. The lower part of the layer is soft and structureless. Non-calcareous.

Knox Silt Loam, No. 33

A_1 (0-2")—Grayish-brown silt loam, containing lime concretions at the surface.

A_2 (2-6")—Grayish-brown friable silt loam, finely granular.

A_3 (6-15")—Light yellowish-brown smooth silt loam, breaks into irregular granules. Calcareous.

B (15-28")—Pale yellowish-brown velvety loose silt loam. No structure. Highly calcareous.

C (28-50")—Pale yellowish-brown silt loam, floury and pulverulent. A few faint gray streaks. No structure. When moist is soft and crumbly, when dry tends to break into plates.

Marshall Silt Loam, No. 34

A_1 (0-2")—Dark grayish-brown silt loam.

A_2 (2-6")—Dark grayish-brown silt loam, granular and friable.

A_3 (6-18")—Dark grayish-brown silt loam, granular, compact in places, but friable.

B (18-22")—Transition zone. Brown heavy silt loam. Some organic infiltrations. Distinctly granular.

C_1 (22-34")—Yellowish-brown silty clay loam, irregular granules.

C_2 (34-50")—Lighter yellowish-brown silty clay loam. Irregular granules, tendency to break into irregular-shaped clods. Non-calcareous.

Knox Silt Loam, No. 35

A_1 (0-2")—Grayish-brown silt loam, smooth to floury.

A_2 (2-6")—Yellowish or grayish-brown silt loam, finely granular.

A_3 (6-14")—Yellowish or grayish-brown silt loam, finely granular.

B (14-34")—Yellowish-brown heavy silt loam, tends to be finely granular. Smoth silt loam but compact. Non-calcareous.

C (34-50")—Pale yellowish-brown floury friable silt loam, highly calcareous. Loose, soft and structureless.

Marshall Silt Loam, No. 36

A_1 (0-2")—Dark grayish-brown silt loam.

A_2 (2-6")—Dark grayish-brown silt loam, finely granular.

A_3 (6-16")—Dark grayish-brown silt loam, to brown silt loam, finely granular in structure. Colored with organic infiltrations, finely granular, almost solid in color.

B (16-27")—Yellowish-brown heavy silt loam. Faint traces of organic infiltrations. Finely granular.

C_1 (27-37")—Yellowish-brown heavy silt loam or light silty clay loam, faintly granular. Color solid except for a few faint gray splotches. Calcareous, very irrgular in content of calcareous material.

C_2 (37-50")—Pale yellowish-brown or grayish-yellow silt loam, exceedingly pulverulent, fine, floury. Highly calcareous. Has many faint gray streaks.

Knox Silt Loam, No. 37

A_1 (0-2")—Yellowish-brown silt loam. A few calcareous nodules.

A_2 (2-6")—Yellowish-brown silt loam, smooth, friable, floury. Tends to be finely granular.

A_3 (6-14")—Lighter yellowish-brown pulverulent, fine granular silt loam.

B (14-34")—Light yellowish-brown silt loam, with occasional faint iron stains and faint streaks of gray. Becomes only very slightly granular in structure in the lower parts of the horizon.

C (34-50")—Lighter pale yellow or grayish-yellow velvety silt loam, highly calcareous. Structureless.

Marshall Silt Loam, No. 38

A_1 (0-2")—Dark grayish-brown silt loam.

A_2 (2-6")—Dark grayish-brown silt loam, granular.

A_3 (6-14")—Dark grayish-brown silt loam, very floury, mellow, faint and almost indistinct granulation.

B (14-28")—Brown light silty clay loam. Some organic infiltrations. No granulation. Non-calcareous.

C (28-50")—Yellowish-brown silty clay loam, friable. Has a few faint grayish-yellow streaks and occasional splotches. No granulation. Calcareous—the lime usually occurring in streaks and spots.

Knox Silt Loam, No. 39

A_1 (0-2")—Grayish-brown floury silt loam.

A_2 (2-6")—Grayish or yellowish-brown friable silt loam, finely granular.

A_3 (6-12")—Grayish or yellowish-brown friable silt loam, finely granular, tending to become poorly granular.

B (12-30")—Yellowish-brown floury fine silt loam, friable and smooth, tends to break into soft clods. Highly calcareous.

C (30-50")—Pale yellowish-brown or grayish-brown silt loam. No granulation. Highly calcareous.

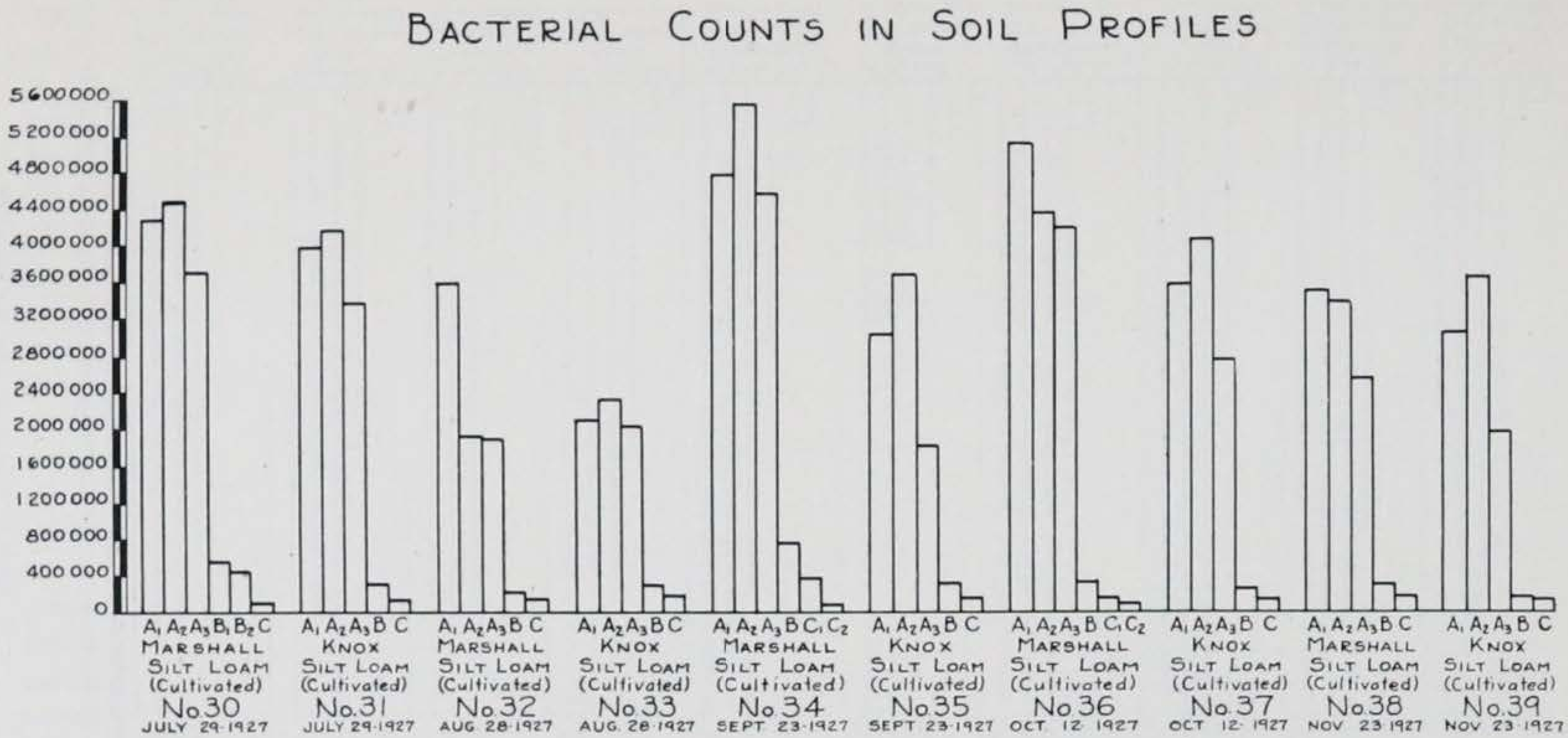

Fig. 16. Bacterial counts in soil profiles—series III.

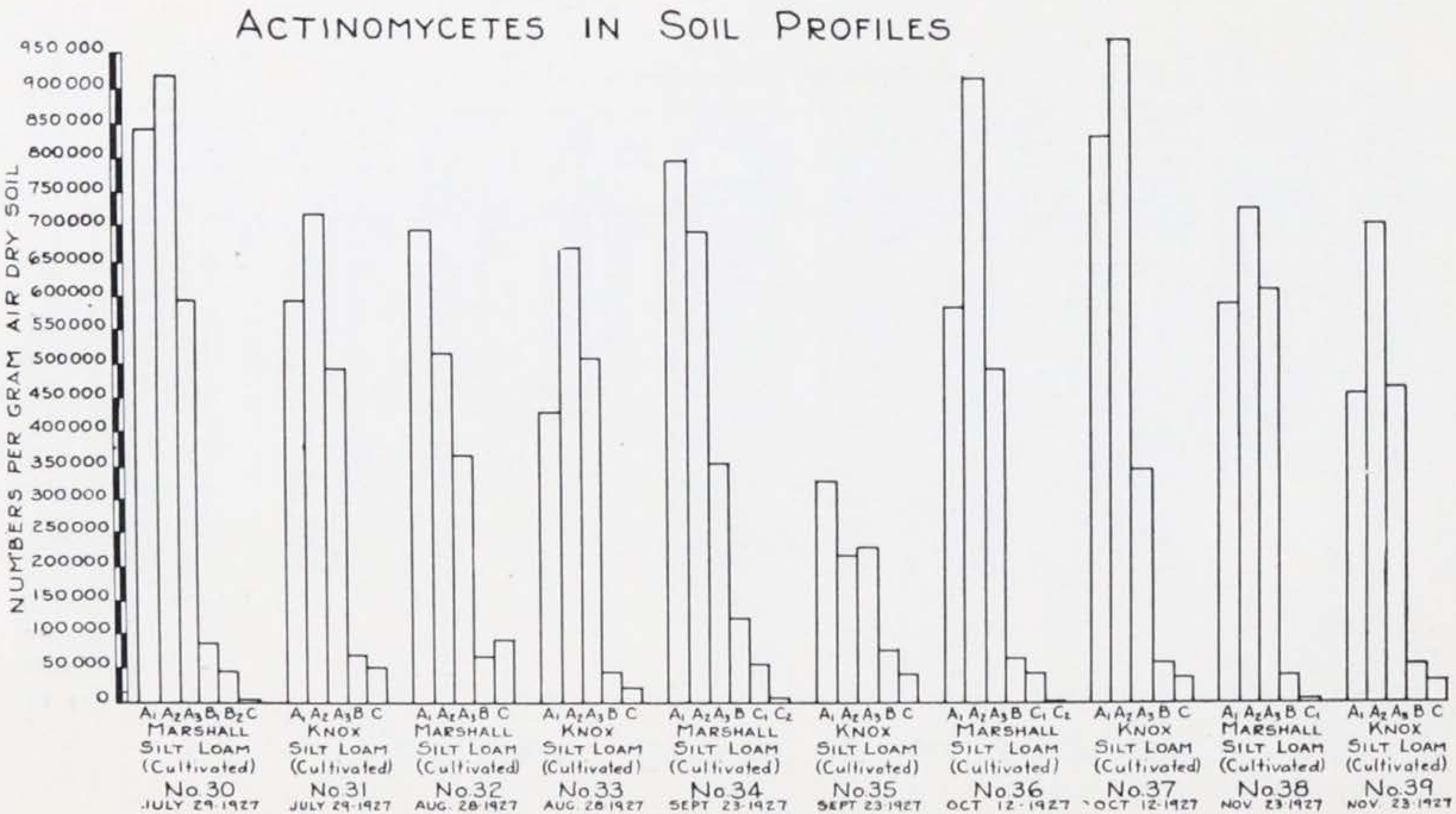

Fig. 17. Actinomycetes in soil profiles—series III.

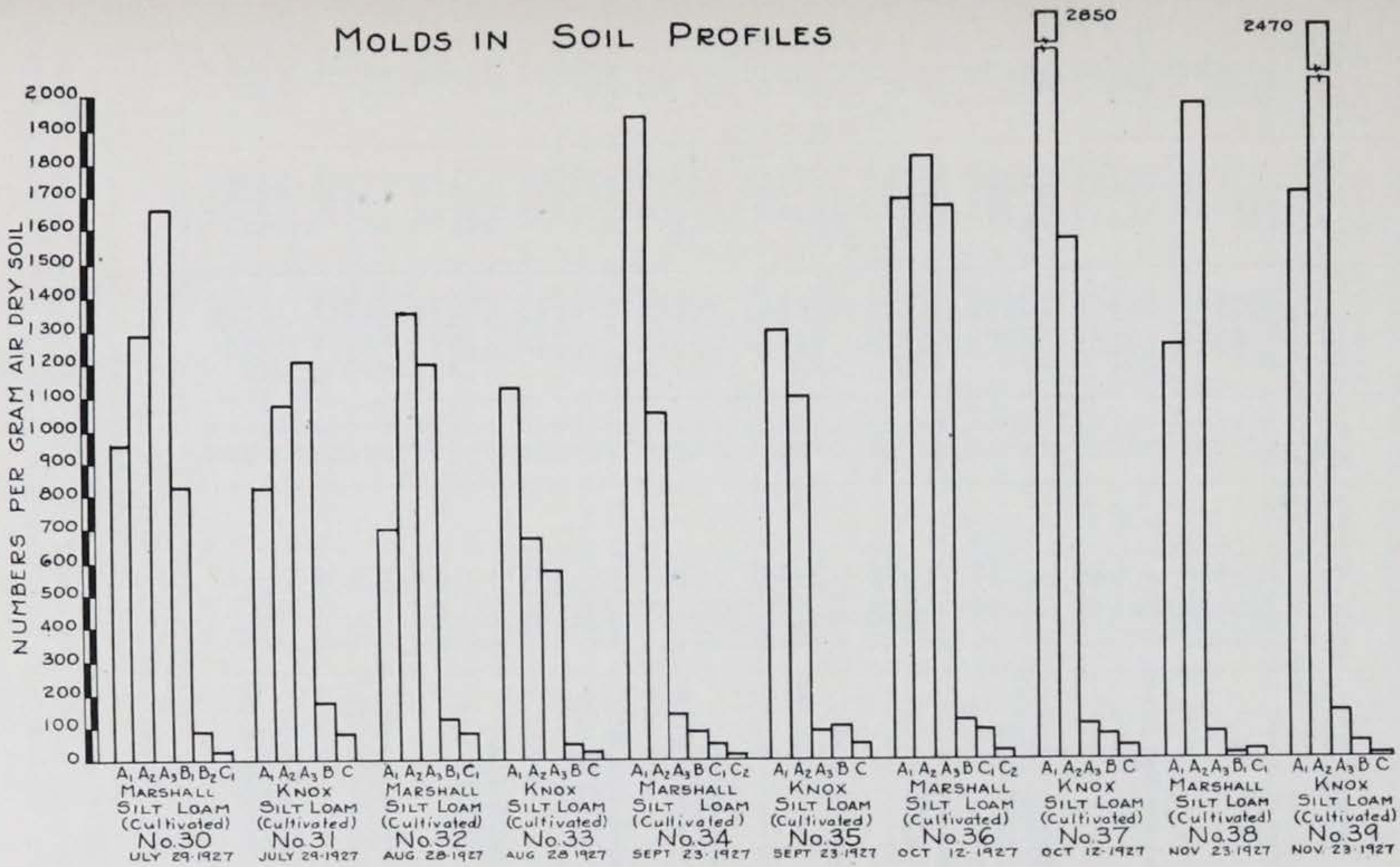

Fig. 18. Molds in soil profiles—series III.

TABLE III. MICROORGANISMS IN SOME SOIL PROFILES IN IOWA

Soil type and date sampled	Depth soil horizon	Percent H_2O	Bacteria per gram air-dry soil	Actinomycetes per gram air-dry soil	Molds per gram air-dry soil
Marshall silt loam	A_1(0-2")	16.0	4,280,000	840,000	950
Number 30	A_2(2"-6")	15.0	4,470,000	920,000	1,290
July 29, 1927	A_3(6"-12")	16.0	3,690,000	590,000	1,660
	B_1(12"-20")	15.5	510,000	82,000	820
	B_2(20"-35")	14.0	410,000	46,000	93
	C (35"-50")	13.5	68,000	5,700	23
Knox silt loam	A_1(0-2")	14.0	3,950,000	580,000	810
Number 31	A_2(2"-6")	16.0	4,160,000	720,000	1,070
July 29, 1927	A_3(6"-16")	15.0	3,370,000	480,000	1,204
	B (16"-30")	14.0	300,000	69,000	162
	C (30"-50")	12.0	125,000	56,000	68
Marshall silt loam	A_1(0-2")	14.0	3,600,000	698,000	695
Number 32	A_2(2"-6")	11.5	1,920,000	511,000	1,350
August 28, 1927	A_3(6"-16")	17.0	1,879,000	361,000	1,200
	B (16"-26")	16.5	179,000	64,900	119
	C (26"-50")	16.0	107,000	86,900	83
Knox silt loam	A_1(0-2")	11.0	2,470,000	426,000	1,120
Number 33	A_2(2"-6")	10.5	2,301,000	670,000	670
August 28, 1927	A_3(6"-15")	13.5	2,080,000	506,000	570
	B (15"-28")	12.0	272,000	46,000	45
	C (28"-50")	10.5	156,000	24,000	24
Marshall silt loam	A_1(0-2")	12.0	4,772,000	795,000	1,931
Number 34	A_2(2"-6")	14.0	5,581,000	697,000	1,041
September 23, 1927	A_3(6"-15")	15.0	4,589,000	352,000	135
	B (18"-22")	12.0	750,000	125,000	79
	C_1(22"-34")	11.0	348,000	56,000	44
	C_2(34"-50")	11.0	55,000	7,860	11
Knox silt loam	A_1(0-2")	8.0	3,040,000	326,000	1,300
Number 35	A_2(2"-6")	10.0	3,660,000	222,000	1,100
September 23, 1927	A_3(6"-14")	12.0	1,818,000	227,000	90
	B (14"-34")	10.0	266,000	77,000	100
	C (34"-50")	7.0	96,000	43,000	43
Marshall silt loam	A_1(0-2")	14.0	5,110,000	581,000	1,650
Number 36	A_2(2"-6")	19.5	4,340,000	911,000	1,810
October 12, 1927	A_3(6"-16")	18.5	4,171,000	492,000	1,630
	B (16"-27")	18.3	305,000	73,000	110
	C_1(27"-37")	17.5	108,000	48,000	96
	C_2(37"-50")	11.5	42,900	4,200	22
Knox silt loam	A_1(0-2")	16.0	3,570,000	830,000	2,850
Number 37	A_2(2"-6")	17.0	4,096,000	960,000	1,560
October 12, 1927	A_3(6"-14")	17.5	2,780,000	350,000	104
	B (14"-34")	14.0	209,000	58,000	69
	C (34"-50")	11.0	89,000	33,000	26
Marshall silt loam	A_1(0-2")	15.0	3,520,000	588,000	1,240
Number 38	A_2(2"-6")	14.5	3,390,000	729,000	1,930
November 23, 1927	A_3(6"-14")	14.5	2,540,000	608,000	67
	B (14"-28")	11.0	277,000	44,000	11
	C (28"-50")	10.5	136,000	10,000	21
Knox silt loam	A_1(0-2")	12.0	3,060,000	454,000	1,700
Number 39	A_2(2"-6")	15.0	3,640,000	705,000	2,470
November 23, 1927	A_3(6"-12")	15.0	2,000,000	470,000	129
	B (12"-30")	14.0	150,000	58,000	46
	C (30"-50")	13.0	80,000	34,000	11

Results of Microbiological Studies

The results of the microbiological studies are given in table III. They are also shown graphically in figs. 16, 17 and 18 for the bacteria, actinomycetes and molds, respectively.

DEPTH

The numbers of microorganisms in the Marshall silt loam and the Knox silt loam, as given in table III and shown graphically in the figures, decreased from the surface or A_1 horizon to the C or C_2 horizon in a very definite way. With the Marshall silt loam, the largest numbers were found either in the A_1 or the A_2 horizon. In some cases the greatest numbers appeared in the surface 2 inches while in other cases larger numbers were found between 2 inches and 6 inches, the A_2 horizon. The differences in general were not very great between these two horizons. In one case, however, a considerable decrease occurred between the A_1 and the A_2 horizons. A decrease occurred in all instances in numbers of bacteria in this soil between the A_2 and the A_3 horizons. The largest decrease in bacterial count occurred from the A_3 to the B_1 horizon. Further decreases, which were not so significant, occurred between the B_1 and the B_2 horizons, and additional decreases were found between the B_2 and the C horizons.

The number of actinomycetes were the highest in either the A_1 or the A_2 horizon, just as was noted in the case of the bacteria. In three of the samples the largest content occurred at the A_2 depth, while in the two remaining samples the largest numbers were found in the A_1 horizon. Decreases occurred in every instance from the A_2 to the A_3 horizon, but in some of the samples the differences were not very great. The largest decrease occurred from the A_3 to the B horizon. Further decreases between the B_1 and the B_2 horizons, between the B_2 and the C_1 horizons, and between the C_1 and the C_2 horizons, were noted in a number of cases, but they were not so large nor significant.

The numbers of molds in the Marshall silt loam decreased considerably from the surface to the lower depths. The decreases were not nearly so large relatively as in the case of the bacteria and actinomycetes. The largest numbers of molds were found in some cases in the A_3 horizon. In all instances, however, the largest numbers occurred in one of the three surface horizons, sometimes appearing at the surface, sometimes in the A_2 horizon and sometimes in the A_3 horizon. The largest decrease appeared from the A_3 to the B horizon. Further decreases from the B to the C horizon were of less significance.

The numbers of bacteria in the Knox silt loam were the largest either in the A_1 or the A_2 horizon. In four instances the greatest numbers were secured in the A_2 horizon. Decreases usually, not large, occurred from the A_2 to the A_3 horizon. Very large decreases occurred from the A_3 to the B horizon, sometimes less than a tenth as many bacteria occurring in the B horizon as in the layer above. Further decreases from the B to the C horizon were found, but they were relatively not so large.

The largest numbers of actinomycetes in the Knox silt loam were generally found in the A_2 horizon, just as in the case of the bacteria. The greatest counts were always obtained either in the A_1 or the A_2 horizon. In other cases, the decreases between these two horizons were not pronounced. In every instance the largest decrease in numbers of actinomycetes occurred between the A_3 and the B_1 horizons. Further decreases from the B to the C horizon were noted, but in general they were relatively small.

The numbers of molds were the greatest in the surface of the Knox silt loam, either in the A_1, the A_2 or the A_3 horizon. There seemed to be wide discrepancies in the numbers of organisms of this group in the various layers of the Knox silt loam. In some instances large decreases occurred from the A_2 to the A_3 horizons, and the decreases below that depth were insignificant. In other instances the largest decreases occurred from the A_3 to the B horizon, and in one case a very large decrease occurred between the A_1 and the A_2 horizons. As has been noted in the previous discussion of other soil types, the numbers of molds do not decrease as rapidly in the lower soil layers as do the numbers of bacteria and of actinomycetes.

MOISTURE

No definite relationship between the moisture content of the various soil layers and the content of microorganisms is indicated. In some of the samples, decreases in moisture occurred from the surface to the lower soil layers, corresponding with decreases in numbers of bacteria, actinomycetes and molds. It might seem in such instances that the moisture content played a part in bringing about the decrease in numbers. In other instances, however, decreases in numbers of microorganisms occurred, sometimes extremely large decreases, while increases in moisture were found. In a few cases increases in numbers of bacteria occurred while decreases in moisture were found. These, however, were exceptional.

The Knox silt loam usually showed a lower moisture content in the surface soil and a lower content of microorganisms, especially bacteria and actinomycetes, than the Marshall silt loam. It might seem, therefore, that the moisture content of the surface soil would be of significance in relationship to the numbers of microorganisms. Other factors, however, are probably involved in determining the differences in numbers of microorganisms in these two soil types. The difference in moisture may be a contributing factor. It is probably not the most significant and certainly not the only factor to be taken into account. In the lower soil layers the differences in moisture content certainly had no relationship to the variations in numbers of bacteria and actinomycetes. The numbers of molds at the lower depths were so small that the results are of little significance.

In some instances larger numbers of microorganisms were found in the lower horizons of the Knox silt loam than in the lower layers of the Marshall silt loam. The moisture content was generally lower, and, hence, there is no correlation. It is recognized, however, that in most of the samples studied in this series, there were no extreme differences in moisture content, either in the various soil layers or in the various soil samples, and consequently, it would not be expected that differences in numbers of microorganisms could be attributed to variations in moisture. Other factors undoubtedly were of more significance. With extremes of moisture, such as a very high content or a very low content, the moisture effect would undoubtedly be more definite.

SEASON

There were differences in the content of microorganisms in the two soils studied at the different dates, but there is no definite evidence of a relationship to season. In the Marshall silt loam there was a decrease from July 29 to Aug. 28, an increase on Sept. 23, a further increase on Oct. 12, and a decrease on Nov. 23 in numbers of bacteria in the surface soil. There were similar fluctuations in the numbers of actinomycetes. The largest number of organisms in the Marshall silt loam occurred in the surface soil on Oct. 12. This may represent the second peak for numbers of organisms in this soil, the earlier peak possibly occurred preceding July 29.

In the case of the Knox silt loam, the numbers of bacteria in the surface soil decreased from July 29 to Aug. 28, increased on Sept. 23, increased still further on Oct. 12 and decreased on Nov. 23. Again these fluctuations may have some relationship to the season, but they are not very definite and the differences in seasonal conditions are certainly not entirely responsible for the variations noted. The numbers of actinomycetes in the surface layers of the Knox silt loam varied in much the same way as did the bacteria. The variations in mold count, both in the Marshall silt loam and the Knox silt loam, were too slight to be significant.

No definite evidence of seasonal effects upon the content of bacteria, actinomycetes and molds is shown by these data obtained on the Marshall silt loam and the Knox silt loam between July 29 and Nov. 23. Had the determinations been carried on thruout the entire season, definite evidences of seasonal effects might have been secured. The most that can be said is that the content of microorganisms appeared to be somewhat larger in the surface layers of both the types late in the season, either in October or November. The largest numbers usually appeared in October and a decrease occurred to November. Decreases occurred between July and August, and increases ordinarily followed a low content of microorganisms in August.

SOIL TYPES

In comparing the Marshall silt loam and Knox silt loam, it appears that the latter soil was usually lower in numbers of bacteria and actinomycetes thruout the surface layers. This may be due, in part, to the lighter color of the Knox silt loam, indicating as it does a lower content of organic matter and, hence, a lower potential plant food or bacterial food supply. There is probably a definite relationship between the color of the soil or the organic matter content and the numbers of microorganisms in these two soils. The soils are of the same texture so no comparisons as to textural effects can be made. Textural conditions in the lower soil layers are the same in the case of both types of soil, and, hence, the differences observed there cannot be attributed to textural changes. The results as a whole may be considered to indicate a relationship of color of the soil type to content of microorganisms.

LITERATURE CITED

(1) Beumer.
1886. Zur Bakteriologie des Bodens. Deut. Med. Wchnschr. Bd. **12**:464-466.

(2) Brown, P. E.
1912. Bacteria at Different Depths in Some Typical Iowa Soils. Res. Bul. Iowa Agr. Exp. Sta. 8.

(3) Caron, A.
1895. Landwirtschaftlich-bacteriologische Probleme. Landw. Vers. Sta. Bd. **45**:401-418.

(4) Chester, F. D.
1904. The Bacteriological Analysis of Soils. Bul. Del. Agr. Exp. Sta. 65.

(5) Eberbach.
1890. Uber das Verhaten den Bakterien in Boden Dorpats. Diss. Med. Dorpat.

(6) Eisenhut.
1901. Uber Terrainauffullungen usw. Diss. Zurich.

(7) Frankel, C.
1887. Untersuchungen uber das Vorkommen von Mikroorganismen in Verschiedenen Bodenschichten. Ztschr. Hyg. u. Infectionskrank **2**:521-582.

(8) Fulles, P.
1891. Bacteriologische Untersuchung des Bodens in der Umgebung von Freiburg. Ztschr. f. Hyg. etc. **10**:225.

(9) Greaves, J. E.
1922. Agricultural Bacteriology. Lea & Febiger, Phila. p. 164.

(10) Greaves, J. E. & Carter, E. G.
1922. The Influence of Moisture and Soluble Salts on the Bacterial Activity of the Soil. Soil Science **8**:251.

(11) Houston, A. C.
1893. Note on the Number of Bacteria in the Soil at Different Depths From the Surface. Edinburg Med. Jour. **38**:1122-1125.

(12) Joffe, J. S.
1929. Soil Profile Studies. I. Soil as an Independent Body and Soi l Morphology. Soil Science **28**:39.

(13) Kebrehl, G.
1906. Studien uber den Filtrations-effect der Grundwasser. Arch. Hgy. Bd. **58**:345-398.

(14) King, W. E. & Doryland, C. J. T.
1909. The Influence of Depth of Cultivation Upon Soil Bacteria and Their Activities. Bul. Kan. Agr. Exp. Sta. 161.

(15) Koch, R.
1881. Zur Untersuchung von Pathogenen Organismen: Bodenuntersuchung. Mitt. K. Gsndhtsamt. **1**:34-36.

(16) Lipman, C. B.
1912. The Distribution and Activities of Bacteria in Soils of the Arid Regions. Univ. Calif. Pub. Agr. Sc. **1**:7-20.

(17) Lipman, C. B.
1919. Further Study on the Distribution and Activities of Certain Groups of Bacteria in California Soil columns. Univ. Calif. Pub. Agr. Sc. **4**:113-120.

(18) Maggiora, A.
1887. Recherche Quantitative Sui Microorganismi del Suolo con Speciale Riguardo all'inquinazione del Medesimo. Gior. Accad. Med. Formo ser. 3t. **33**:153.

(19) Miquel, P.
1897. Sur la Longevite des Germes des Bacteries dans les Poussieres et dans le Sol. Ann. de micrographie 9, p. 199. ref. Jahresber. uber die Fortschriete in der Lehre von den Garungsorgamsmen 8, p. 52.

(20) Proskauer, B.
1882. Uber die Hygienische und Bautechnische Untersuchung des Bodens auf dem Grunstucke der Charite and des Sogen. "Alten Charite-Kirchhofes." Bakteriologisches Verhalten des Bodens. Ztschr. Hyg. u. Infectionskrank Bd. **11**:22-24.

(21) Reimers, J.
1889. Uber den Gehalt des Bodens in Bacteria. Ztschr. Hyg. u. Infectionskrank. Bd. **7**:319-346.

(22) Snow, L. M.
1926. A Comparative Study of the Bacterial Flora of Wind Blown Soils. I. Arroyo bank soil Tucson, Arizona. Soil Science **21**:143-161.

(23) Stoklasa, J. & Ernest, A.
1905. Uber den Ursprung, die Menge und die Bedeutung des Kohlendioxyds in Boden. Centbl. Bakt. (etc) Abt. 2, Bd. **14**:723.

(24) Waite, H. H. and Squire, D. H.
1911. A Comparative Study of the Bacterial Content of Soils From Fields of Corn and Alfalfa. 24th Ann. Rpt. Neb. Agr. Exp. Sta. p. 160-177.

(25) Waksman, S. A.
1916. Bacterial Numbers in Soils at Different Depths and in Different Seasons of the Year. Soil Science **1**:363.