
Review: Some Recent Work on Physical Edaphic Factors

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NOTICES OF PUBLICATIONS OF GENERAL BEARING

SOME RECENT WORK ON PHYSICAL EDAPHIC FACTORS

- (I) **Hanley, J. A.** "Estimation of the surface of soils." *Journ. Agric. Sci.*, **6**, 1914, pp. 58-62.
- (II) **Cannon, W. A.** "A manometer method of determining the capillary pull of soils." *Plant World*, **18**, 1915, pp. 11-13.
- (III) **Keen, B. A.** "The evaporation of water from soil." *Journ. Agric. Sci.*, **6**, 1914, pp. 456-475.
- (IV) **Russell, E. J.**, and **Appleyard, A.** "The atmosphere of the soil." *Ibid.*, **7**, 1915, pp. 1-48.
- (V) **Russell, E. J.** "The nature and amount of the fluctuations in nitrate contents of arable soils." *Ibid.*, **6**, 1914, pp. 18-57.
- (VI) **Cannon, W. A.** "On the relation of root growth and development to the temperature and aeration of the soil." *Amer. Journ. Bot.*, **2**, 1915, pp. 211-224.
- (VII) **Daikuhara, G.** "Ueber säure Mineralböden." *Bull. Imp. Agric. Exp. Sta. Japan*, **2**, 1914, pp. 1-40.
- (VIII) **Hutchinson, H. B.**, and **MacLennan, K.** "The lime requirements of certain soils." *Journ. Agric. Sci.*, **7**, 1915, pp. 75-105.
- (IX) **Lipman, C. B.**, and **Sharp, L. T.** "Effect of moisture content of a sandy soil on its nitrogen fixing power." *Bot. Gaz.*, **59**, 1915, pp. 402-406.

As has been pointed out with especial clearness by Russell ("Soil conditions and plant growth," London, 1915), in considering any soil in its relation to plant growth it is necessary to take into account not only the intrinsic properties of the soil itself, due to the physical and chemical nature of its constituent parts, but also the extrinsic properties impressed on it by topographical and climatic factors. That is, not only the distinctively soil characteristics as formerly understood but the conditions of broader range involved in the term edaphic environment must be included in the modern conception of the soil. The soil is very much the result of circumstances, its characters being determined in part by the rock from which it was derived and in part by subsequent events, particularly the temperature and water supply it happened to obtain—in other words, the soil climate; and a given set of mineral particles may give rise to soils wholly different in character and in natural flora. A convenient grouping of the phases of the threefold aspect of physical, chemical and biological considerations, suggested in a recent paper (de Forest, "Recent ecological observations," *Proc. Soc. American Foresters*, **9**, 1914), is as follows: (1) the nature, physical and chemical, of the soil particles; (2) the character, amount and distribution of the precipitation; (3) the position of the soil in relation to the topography, and its exposure, shading, surface and other factors affecting its relative temperature and water supply;

(4) the depth of the soil; (5) the nature of the subsoil, especially its perviousness to air, water and plant roots; (6) the soil flora and fauna.

The recent works cited above and brought together here for summarising deal with various aspects of the edaphic environment, that is, with various questions regarding soil conditions, soil fertility and the growth of higher plants which root in the soil and of the micro-organisms which live therein. The publications here dealt with are grouped under one heading because broadly they all deal with *physical* phenomena (including colloidal) of the soil in relation to the growth of plants and of soil micro-organisms. It is proposed in a later number of this JOURNAL to bring together in a similar manner some of the more recent publications dealing with the more distinctively chemical and biological aspects respectively of the edaphic environment. It need hardly be pointed out, however, that any such grouping must necessarily be quite artificial, since the different factors making up this environment are intimately related to each other and there is consequently much overlapping and dovetailing among the various investigations which are being carried on. It will be noted that many of these investigations are by workers in agricultural science, but it is becoming increasingly evident that the best results in ecological work will come not alone from the devising of original methods but also from the adaptation of the methods used in Agriculture to the particular purposes of Ecology, and that nothing is more desirable for the progress of both Ecology and Agriculture than that workers in each of these branches should keep in close touch with the methods used and the results obtained by those in the other.

(I) The author describes a method for estimating soil colloids by means of dyes, which can be used, with suitable modifications, to determine and compare the total surface areas of soils made up of different-sized particles—a point of great interest in connexion with aeration, water-holding capacity, capillary pull and various other characters of the soil.

Methyl violet was used, as this colour undergoes only a slight change even after prolonged contact with the soil; but it was shown to be useless to employ dye solutions of the same strength for soils of the same type, e.g. for sands, 1 gram; for loams, 2 grams; for clays, 3 grams of dye per litre. The reaction is a typical absorption and the quantity of dye taken up depends on the strength of solution used, an equilibrium setting up between dyed soil and dye solution. For comparing surfaces of soils it is therefore necessary to estimate the dye absorbed when the *dyed* soils are in contact with supernatant dye solutions of the same strength. A series of dye solutions has therefore to be used for each soil and the appropriate concentration picked out by trial.

(II) The method commonly used for determining and comparing the capillary properties of soils is the simple one of placing the soil in a glass cylinder with the lower end set in water, the ascent of the water being measured directly. The author describes an apparatus which he has found, from use at the Tucson Desert Laboratory, to be of value as a convenient means of determining the capillary pull of soils and of demonstrating this important physical character in a striking manner. The apparatus is simple, consisting of a U-shaped mercury manometer with open ends, a soil container of about 500 c.c. capacity, and a 500 c.c. water reservoir. The reservoir is connected with a glass T-tube having a three-way cock, a rubber tube connects one free end of the T-tube with the manometer and another (relatively long) rubber tube connects the third end of the T-tube with the soil container. The whole is arranged so that water, to the exclusion of air, fills the tubes connecting container, reservoir and manometer, and the reservoir and container are about on the same level so that if the cocks are left open water will stand about equally near the upper edges of both. A plug of glass-wool is put in the bottom of the container to prevent escape of soil, the reservoir is about half filled with water, and with the cocks joining reservoir and container open the container is raised or lowered enough to bring

the water in it to a depth of about 2 cm. when the cocks are closed. The container is then filled with soil, the cocks opened to allow rise of water and its flow out of reservoir, and the soil at once run through several times with a glass rod to promote its settling and to prevent premature collection of air bubbles at the bottom of the container; all this time water is flowing out of reservoir into container and is rising in the soil. Then the cock below the reservoir is turned so as to cut off the flow of water from it and at the same time to connect container with manometer. The position of the mercury is observed at this moment and the rise is watched until the upward movement ceases or until the mercury falls; the uppermost point reached by the mercury is considered the measure of the capillary pull of the soil under the conditions of the test.

Tests were made with sand and with clayey soil (adobe), separate and also mixed in equal parts, in all cases coarsely sieved to remove small pebbles and then separated into two parts by sifting through 20 and 40 mesh sieves (20 and 40 meshes to the inch). For the mixed soil the highest point reached by the mercury was 22.5 mm.; the 20-mesh sand registered 6 mm. and the 40-mesh sand 9.5 mm.; unsifted adobe, 20-mesh, stood at 18 mm., and 40-mesh at 25 mm., but the capillary pull of the sifted adobe soil was not easy to determine, owing to its peculiar physical nature. An interesting and characteristic feature of the tests with sand, especially coarse sand, was that the mercury rose very quickly at first, but for a brief time, after which it maintained an even height for a long period—e.g. the mercury in a test with 40-mesh sand remained at 9.5 mm. for over three hours.

(III) Water supply is a soil factor of prime importance in determining not only the growth of plants but also of micro-organisms whose activity plays such an important part in soil fertility, but although much information is available as to the percentage of water present in soils under various conditions, a difficulty in the way of discussing these data adequately has been the fact that so little was known regarding the state in which the water actually exists in the soil. From field observations made at Rothamsted it became evident that the simple theory that the water is present as free films merely suspended on the soil particles could not be correct. The method adopted by the author was to study the rate of evaporation of water from the soil. The relation of water to soil was found to differ considerably from its relation to sand. The soil colloids diminish the tendency to evaporation, the effect being so definite that it can be represented by a mathematical formula from which a curve can be drawn that agrees entirely with the experimental curves. One of the most interesting results is that all the water in a normally moist soil is held in the same way and that there is no break in physical state; the distinction formerly made between free water and hygroscopic water could not be found in these experiments.

The following is a summary of the author's chief results.

The evaporation of water from sand, silt, china clay, and ignited soil is a relatively simple phenomenon which can readily be explained by the known laws of evaporation and diffusion. The evaporation from soil is more complex, something being present which operates in making the relation between the soil and the soil water of a different and closer nature than in the case of sand, etc. The effect is not due to the soluble humus, for the removal of this material from the soil does not appreciably affect the phenomena of evaporation. Any possible effect of the insoluble organic matter is largely eliminated by the consideration that *ignited* sand or silt behaves like the *unignited* material.

But when the colloidal properties of the clay are destroyed by ignition, the evaporation curve is completely altered, and becomes identical with that given by sand or silt. Again, evaporation from china clay, which shows very feeble colloidal properties, is of the same character as that from sand. We may infer then, that the colloidal properties of the clay fraction are partly, if not mainly, responsible for the characteristic shape of the evaporation curve from soil.

Further information on the process of evaporation has been obtained by a mathematical examination of the rate curve for soil. Two factors have been distinguished, which operate over practically the whole range of water content dealt with in these experiments. In the first place the initial proportionality between water content and time observed with sand is not seen with soil, the curve being more exponential in character. This indicates that the relationship of water to soil is quite different from its relationship to sand, a circumstance which has been traced as already stated to the colloids. This relationship has at present only been expressed empirically but it is probably connected with the relation between vapour pressure and moisture content. But there is clearly something else at work, for the curve is not of a simple exponential type. It is necessary to allow for another factor: the effect on the rate of evaporation of the decreasing water surface in the soil, the surface obviously diminishing in area as evaporation continues.

The equation finally developed is:

$$A \frac{dw}{dt} = \sqrt[3]{\left(\frac{ws}{100} + 1\right)} [2.303 \log_{10} (w + K) - \log_e K],$$

where $\frac{dw}{dt}$ = rate of evaporation, w = percentage of water present by weight, s = specific gravity of the soil, A and K = constants.

(IV) Equally important with the water supply in its relation to plant growth is the air supply in the soil. The authors' periodical analyses extending over two years on several typical plots at Rothamsted have shown that the free air in the soil pore spaces differs only slightly from atmospheric air in regard to oxygen content, but there is a greater difference in carbon dioxide content. These results agree so closely with those obtained elsewhere that we may regard the similarity of soil air to the atmosphere as generally true; but the investigation revealed something that had apparently not been previously observed. It was found that in addition to the free air of the soil there is a second atmosphere dissolved in the soil moisture and colloids, which is entirely different in composition, containing no free oxygen but mainly carbon dioxide and some nitrogen. It is this atmosphere which is in most intimate contact with the plant roots and micro-organisms, and its lack of oxygen proves that the oxygen is used up more rapidly than it is renewed by solution from the free air.

These results (summarised more fully in the succeeding paragraph) are of great interest in relation to biochemical changes going on in the soil, and form an important contribution towards the fuller knowledge of the conditions under which life exists in the soil—a knowledge which is essential in order to unravel the tangled story of the relations between soil micro-organisms and the growth of plants and to correlate the information that has accumulated regarding the bacteria, fungi and protozoa inhabiting the soil.

The top 15 cm. layer of the soil was selected as proper for the experimental work, although there is in fact but slight variation throughout the first 30 cms. Different surface soils were examined, some being under a crop, others bare, some manured, others unmanured. Minor fluctuations in composition were shown, but the broad conclusions are true of all the types selected. The total pore space is about one-third of the total volume of the soil; from 10 to 12 % of this space is occupied by soil air, the remainder being occupied by water. The soil air contains oxygen, nitrogen, and carbon dioxide. In composition it is generally similar to the ordinary atmosphere, but contains less oxygen, more carbon dioxide, and, usually, more nitrogen, the differences being due to the absorption of oxygen and the evolution of carbon dioxide by the inhabitants of the soil. Diffusion is constantly tending to make the proportions in soil air and in ordinary air equal. The absolute differences are small. For example, the average percentage

composition of soil air from arable land was oxygen 20·6, nitrogen 79·15, carbon dioxide ·25, but taking relative differences it is seen that (carbon dioxide in ordinary air being taken as ·04 %) the last-named gas is six times as abundant in arable soil air as in ordinary air. There is a large seasonal variation in the proportion of carbon dioxide in soil air, which reaches a maximum in late spring and again in late autumn, at which periods rapid biochemical changes are taking place in the soil. The highest and lowest percentages of carbon dioxide found in the soil air were ·37 and ·08 respectively. The free air filling the soil spaces is not the only air in the soil, for on subjecting the soil to diminished pressure it was found that the vacuum persistently began to fall soon after exhaustion appeared to be complete. Thus gas was being evolved from the soil and was found to be composed of over 90 % of carbon dioxide, with a small percentage of nitrogen and a still smaller percentage of oxygen. The gas is dissolved in the soil moisture and other soil constituents. Consequently the soil conditions are such that both aerobic and anaerobic organisms can find suitable surroundings. In the appendix to the paper is given a description of the apparatus for collecting the soil air.

(V) As is well known, the nitrogen compounds in the soil, whether occurring naturally or added as manure, break down under the action of micro-organisms to form nitrates and gaseous nitrogen, the former being wholly valuable and commonly limiting the fertility of the soil, while the latter is apparently wholly waste and of no value to plant growth. The study of these important changes, hitherto made chiefly in the laboratory, has now been carried into the field, and the author gives the results of periodical determinations made during five years of the amount of nitrate present in soils at Rothamsted under varying treatments. It was found that the rate of accumulation of nitrates is usually rapid in spring, falls off in summer, rises in autumn, and falls again in winter; hence two maxima occur, one in spring and the other in autumn, with minima in summer and winter. But the amount of nitrate in the soil at any time only represents the balance of gains over losses, and cannot be taken offhand as a measure of the rate of production of nitrates, the quantity that is really required. A simple solution of this difficulty was at last found. If the curves showing the amount of some other substance produced in the same way as the nitrate but lost in a different way are of the same general shape as the nitrate curves, it is obvious that the shape is due mainly to the production factors; if on the other hand the two sets of curves are different in shape the loss factors control the situation. The carbon dioxide in the soil air satisfies these requirements; it is produced like nitrates by bacterial action, but it is lost largely by gaseous diffusion and only in very wet weather by leaching. Carbon dioxide was therefore determined simultaneously with nitrates, and the curves show a marked similarity except that the increases in nitrate came later. Thus we may conclude that the curves are in the main production curves. In winter the curves follow the temperature pretty closely, but through the rest of the year they follow the rainfall and to a less extent the moisture. There is evidence that the dissolved oxygen in the rain may be a factor of importance particularly as it ensures renewal of the dissolved atmosphere. After a heavy rainfall the carbon dioxide in the soil air begins to increase followed later by an increase in nitrates. A certain number of bacterial counts were made, and these showed that a rise in bacterial numbers preceded the autumn increase in carbon dioxide.

In almost all the soils examined the accumulation of nitrate took place most rapidly in late spring or early summer; after this there was usually little if any gain, and frequently a loss, but in the hot dry autumn of 1911, and again in 1913, the accumulation continued in some of the soils right on till September. During the winter loss of nitrate took place; this was more marked in the wet winter of 1911–1912 than in the drier winter of 1908–1909. The fluctuations in nitrate content are more marked on loams than on clays or sands.

Clays lose less of their nitrates in winter, but, on the other hand, they accumulate smaller amounts in June and July. Sands lose much of their nitrates in winter and do not accumulate very large amounts in summer. It appears that the main loss in winter is due to leaching and not to denitrification. On comparing the nitrate content of cropped and fallow land it is found that during late summer and early autumn the fallow land is the richer, even after allowing for the nitrate taken up by the crop. The question whether the growth of a crop exerts any depressing effect on the rate of nitrate production in the soil is under further investigation. The rapid rise in nitrate content in spring does not usually set in immediately the warm weather begins; there is a longer or shorter lag. There are indications of greater bacterial activity in early summer than later on, a phenomenon readily explicable on the view that the soil population is complex and includes organisms which are detrimental to the activity of bacteria, but which are, on the whole, more readily put out of action.

The supply of nitrate to the plant is known to be a factor of prime importance in plant growth. Similarly it is found that the factors which determine the accumulation of nitrates in the soil also play a great part in determining the amount of crop production. Thus heavy winter rainfall, which washes out nitrates, tends to reduce crop growth; on the other hand, hot dry summers, succeeded by dry winters, are shown to be favourable to nitrate accumulation, and therefore to crop growth. A series of field experiments has been started to ascertain how these spring and autumn periods of biochemical activity may best be utilised for crop production.

The other reaction, the loss of gaseous nitrogen from the soil, is under investigation in the Rothamsted laboratory, and a parallel investigation of a manure heap is being made simultaneously. These experiments have indicated a hitherto unsuspected source of loss in the heap and, fortunately, a way of avoiding it. It has been found that nitrates are formed on the outside of the heap, but readily decompose if they are washed inside. Watering a heap sufficiently to effect this but not enough to cause leaching was found to increase the loss considerably; on the other hand shelter from rain, together with compacting, reduced the loss practically to zero over a period of three months' storage. The technical value of this work is very considerable, but of even greater significance is its application in elucidating the loss of gaseous nitrogen from soil. In at least one direction a soil particle containing organic matter resembles a manure heap: it is surrounded by a free atmosphere containing some 20% of oxygen so that nitrate production goes on at its surface; it also has a dissolved atmosphere devoid of oxygen and therefore supplying one of the essential conditions for denitrification. This resemblance furnishes a working hypothesis which is now being developed.

(VI) From his work on desert plants, the author finds that while there is great diversity in root development in these plants, seen even in a single habitat where all the species are apparently subject to similar environmental conditions, at the same time the same species when growing in another habitat which differs considerably from the first one may still retain each its characteristic type of root system. Hence it seems probable that there are environmental conditions, to a degree apart from the soil *per se*, which are held in common by otherwise unlike habitats, to which the developing roots react in characteristic manner and which thus may be of determining importance in shaping the direction of root development. Among the most striking of such common factors, which lend themselves readily to experimentation, are soil aeration and soil temperature, hence in preliminary experiments directed to a solution of the general problem relating to differences in root development the reactions of roots to aeration and temperature were taken up. As to aeration, it is apparent that root systems lying close to the surface of the soil, e.g. that of *Fouquieria splendens* and especially *Opuntia versicolor* and other

cacti, must hold a very different relation to the atmospheric air than root systems which are deeply placed (e.g. *Prosopis velutina*). Cultures showed that the roots of *Opuntia* had a very definite reaction to an abundant supply of air, but the results of direct aeration experiments were not entirely consistent, and the present paper is devoted mainly to the reaction of roots to various soil temperatures and to a consideration of the results as factors in the development of root types and in the distribution of the species.

The soil acts as a reservoir of heat, since there is usually less loss of radiation at night than accumulates in the soil by day, hence it is a great temperature stabiliser. Though the temperature of the soil varies considerably, especially with depth, in the colder seasons the superficial soil may show a lower temperature than the deeper soil. The amplitude of the daily and seasonal variations also varies inversely as the depth, hence root systems extending close to the surface are subject to maximum temperature changes and in this respect their temperature relations form a marked contrast to those of deeply lying roots. Among the factors that directly affect soil temperature are colour, moisture content and slant of surface with respect to the position of the sun; of these, moisture content is the most important, since water has a specific heat about five times as great as that of the solid soil constituents. The author gives a figure showing the theoretical efficiency of different exposures for several angles, to show the importance of slope as a direct cause of temperature variation in soils, particularly where the soil is poorly protected by vegetation, as in the desert, though no extended studies have yet been made on this subject. Curves are given of records taken for several years at the Desert Laboratory of the soil temperatures at depths of 15 cm., 30 cm. and 2.6 m., showing that from April to August the shallowest soil is the warmest, in September the 30 cm. horizon has the highest mean temperature, and during winter the highest temperature occurs in the deepest soil. Another instructive viewpoint is obtained by integrating the temperatures of these records, and the results of such temperature summation of all soil temperatures above 10° C. is given graphically, showing that the amount of heat in the soil, at a depth of 30 cm. beginning with April, was greater than the amount at the 15 cm. horizon, though the latter provided the higher maxima; the maximum amount at the 15–30 cm. depths was received in June, while the maximum amount at 2.6 m. was not received until August; there was a sudden drop in temperature at the shallower depths in July, associated with the summer rains which began at that time, but the penetration of the moisture did not serve wholly to arrest the upward temperature movement at 2.6 m. until the following month. By drawing horizontal intersecting lines to represent integrations of temperatures averaging 20° and 30° it is shown what portion of the entire year has soil temperatures averaging more than 20° and 30° and at what depths; and the two lines also delimit in a general way the seasons of root growth and to some extent also shoot growth of the shallowly rooted and deeply rooted plants—thus vegetative activity is seen in *Prosopis velutina* in March–April, while shoot growth as well as active root growth in *Fouquieria splendens* and in *Opuntia versicolor* does not occur until midsummer. Hence roots which occupy different soil horizons in the same habitat are exposed to widely different temperatures, not only in winter when there is little or no root growth but also in summer when root growth is most active.

The author next considers how differences in soil temperatures influence the root growth rates of species having unlike root systems, *Prosopis* being taken as representing the deeply penetrating type and *Fouquieria* and *Opuntia* that which lies near the surface, and the experiments being made on cultures of seedlings and young plants grown in tubes, boxes and garden beds. Data are given of the actual relative growth rates, the chief fact established being that root growth occurs in *Prosopis* at a temperature so low as to be unfavourable for growth in the shallow-rooting species.

In his general discussion the author points out that during the season of most active root growth, midsummer, three features in the root environment are of special importance—moisture, temperature, and aeration of the soil. At this time, owing to the rains, the soil contains sufficient moisture for the developing plants, while the temperature at the depths attained by roots is also suitable for their growth. Near the surface, in fact, an optimum temperature for root growth obtains for a rather long period, and within limits the moisture content increases and the temperatures decrease with depth, but in addition there is the condition of the aeration of the soil. Air movements in adobe (clayey) soil are profoundly influenced by the addition of water; that there is active movement of air in air-dry soil and that the movement is strikingly affected by moisture is shown by the fact that a tube 30 cm. long filled closely with air-dried adobe requires only 0.5 cm. water pressure to cause an active air current to pass through, while it is extremely difficult to add so little water that the air flow is not quite stopped, and of course if enough water is added to puddle the soil it is impossible to force air through. Hence with the rains of summer and consequent thorough wetting of the soil the movements of the soil atmosphere are greatly modified, and the ingress and egress of air cut down to a marked degree or entirely stopped. From both observation and experiment it may be assumed that it is owing to unlike responses to environmental conditions that the characteristic differences in the mature root systems are largely if not wholly due. Thus as regards the *Fouquieria* and *Opuntia* it appears that low soil temperature is a factor limiting downward root growth, while this factor affects the root growth of *Prosopis* very little; and from the behaviour of the roots of *Opuntia* in cultures it appears that root branching in this plant is very closely related to good soil aeration, while whatever may be the factors that control root branching in *Prosopis* it is probable that abundant aeration is not an important one. Thus root growth and branching in *Fouquieria* and *Opuntia* take place mainly near the surface where the aeration-temperature conditions are favourable, and the root systems of these plants are superficial; while as the lower temperature of the deeper soil does not inhibit root growth in *Prosopis*, and the roots are not so restricted in the aeration relation, deep penetration results. Thus through unlike physiological response there results strikingly dissimilar root growth and development.

Very little work has been done on the relation of root reaction and root type to species distribution, though the results of experiment and observation suggest the possible importance of this relation. The basis of the significance of the root factor in this connexion lies in two general features—the root character itself and the manner of response of roots to the soil environment. In the former case, especially in obligate deeply penetrating roots, the limiting factor appears to be only the depth of the soil; but in such species as have generalised roots and roots which are essentially shallowly placed the condition is different—the limiting factors here relate to root response to such environmental soil factors as moisture, aeration and temperature. Other distributional factors being equal, the species having the most plastic roots, and roots capable of the most catholic responses to the soil environment, or both, should also be the most widely distributed, and conversely species that are sharply limited in root growth by soil conditions, or whose roots are not plastic, should also have the most restricted distribution.

(VII) Among factors which control the activity of the soil organisms and therefore the growth of plants, apart from those referred to in the foregoing paragraphs, two of importance may be mentioned here, namely, a source of energy and the presence of basic material. The former is provided by the residues of plants and constitutes one of the most interesting of the relationships between plants and soil micro-organisms. The exact effect of the basic material in practice usually means calcium carbonate, and soils are described as sour or acid when calcium carbonate is lacking. The author has in addition

to his own observations on the soils of Japan and Korea collected data relating to acid soils in various parts of the world, with interesting results. He finds that more than 75 % of the soils of Japan and Korea are acid, while those of China and of Europe show little or no acid, and he attempts to correlate the differences as to acidity with differences in geological formations and in climatic conditions. Soils of acid rock origin show the most prevalent acidity, those of basic origin less, while those of laval ash are usually free from acids. Mesozoic formations are most commonly acid; tertiary, palaeozoic and diluvial come next; and alluvial formations are least acid. He finds that more than half of the cases of acidity investigated are due to aluminium and iron compounds of acid reaction which are adsorbed by the colloids of the soil and set free on the addition of such fertiliser salts as chloride, sulphate or nitrate of potassium, or sodium chloride. In such soils the addition of neutral salts alone proves detrimental, while the addition of neutral salts plus lime is beneficial to a marked degree. Although the fact that the negative colloids of the soil render lime-poor soils acid by adsorbing the basic ion of neutral salts and setting free the acid has been known for some years, and is not a newly discovered source of soil acidity as the author claims, the paper is of much interest and usefulness, since in addition to bringing together a large amount of literature he describes what may prove to be useful methods of testing for as well as quantitatively determining soil acidity; but the problems connected with the acid-forming processes in the soil, and in particular with the colloidal phenomena concerned, are still in need of investigation from various points of view.

(VIII) Although the results presented in this paper are mainly of agricultural interest, one of the chief points brought out being that lime (calcium oxide) differs fundamentally from calcium carbonate in its effects when applied to correct soil acidity, some are of actual or potential ecological interest, while the methods used in the investigation are such as might with advantage be applied in ecological work. The authors find that while the addition of calcium carbonate (i.e. chalk, limestone, marl, etc.) merely corrects the soil reaction, calcium oxide (quicklime or caustic lime) not only does this, but in addition, if applied in sufficient amount, produces certain effects classed under the head of partial sterilisation. Failure to recognise this double effect of caustic lime has led in the past to a misinterpretation of experimental results.

In order to determine the right amount of quicklime to apply to the five different soils which were subjected to examination, definite weights of soil were taken and, after being moistened, were treated with different amounts of quicklime ranging from .1 to 2.0 % of the weight of air-dried soil. At a certain critical point, different for the different soils, the soil was found to be distinctly alkaline, and from 5 to 10 c.c. of decinormal acid were required to neutralise the whole filtrate. The different amounts of quicklime required to reach this critical point ranged from .3 to 1 % of the soil taken, and it was further found that the critical point also marked the following: (1) inhibition of nitrification, (2) destruction of the larger protozoa, (3) maximum growth of plants subjected to pot experiments, (4) flocculation point.

To determine whether a soil is acid and therefore requires a dressing of lime it is not sufficient to determine whether or not the soil contains carbonate of lime, since a number of normal soils have been recorded which are neutral and yet contain no carbonate of lime. The authors review the numerous methods which have been adopted by different investigators for the determination of soil acidity, and reject them all as being inferior to the calcium bicarbonate method which they have devised. By treating an excess of carbonate of lime suspended in water with carbon dioxide generated by means of "sparklets" or otherwise a solution of the bicarbonate is obtained which after filtration can be diluted to approximately .02 N strength. A known weight of the soil to be examined is shaken

for three hours with this solution, and at the end of the period the amount of unabsorbed alkali is determined by standard acid solution in the usual manner. Soils showing a positive lime requirement by this method have been found to respond distinctly to the application of carbonate of lime by increased ammonia and nitrate production in laboratory experiments, and by greater plant growth in pot culture and field work.

(IX) Since the well-being of the beneficial soil bacteria is a vital factor in the maintenance of soil fertility, it is quite as important a question to determine the relation of the moisture content of a soil to its bacterial activity as to ascertain the relation thereof to the growth of the plant itself. Very little work appears to have been done on these lines, hence the results obtained by the authors of this paper are of special interest. Previous writers had found that the number of soil bacteria and the rates of ammonification and nitrification increased with soil water content up to a certain point and diminished again when moisture was supplied in greater quantities. The present paper deals however with the nitrogen fixing bacteria in their relations to moisture. From their experiments with a light sandy soil from a walnut grove in California, the following results were obtained. Since nitrogen fixation by a soil's natural flora is the algebraic sum of the activities of various classes of bacteria, both aerobic and anaerobic, it follows that the greatest nitrogen fixation will occur at a moisture content very favourable for the most active forms of these bacteria and yet not entirely unfavourable for the less potent forms, and vice versa. In the soil in question this point appeared to lie between the limits of 20 % and 24 % of moisture (air dry basis), hence it would appear that the aerobic forms grow best with 20 % moisture content, while at higher percentages of moisture up to 24 % the anaerobic forms become more active while the aerobic forms are depressed in their nitrogen fixing power. Nitrogen fixation is however very active even with low moisture content of the soil; thus with 8 % very considerable quantities of nitrogen are fixed, and appreciable quantities with moisture content of only 4 %. Taken as a whole, the nitrogen fixing flora of the soil used, which may be taken as a criterion for a large variety of sands and sandy loams, behaves much more like the ammonifying than like the nitrifying flora with respect to moisture; this agrees with other results from the point of view of factors other than soil moisture content which have been obtained with respect to the behaviour of these three groups of organisms. While the authors believe that changes in the physical constitution of a soil may seriously modify the points of maximum and minimum bacterial activity with a given moisture content, they point out on the other hand that the more exact determination of available moisture in all soils, as advocated by Briggs, will probably indicate but slight variations from the optimum and minimum moisture contents necessary for the activity of soil organisms as determined by them for the nitrogen fixing flora and by previous writers for the ammonifying and nitrifying flora.