THE ORGANIC CONSTITUENTS OF SOILS[1]

THE reports on the various phases of soil studies by the investigators who have preceded me in this symposium must have impressed you with the fact that the subject of the soil's fertility and infertility is by no means a simple matter of arithmetic, which involves only a few of the mineral constituents of the soil. It must also have become clear to you that the problem of the soil's fertility or infertility has not been solved by the application of these simple arithmetical means based on soil analysis or by the crop statistics accumulated in the years which have elapsed since Liebig first announced his views on soil fertility which gained for him for all time the title of "Father of Agricultural Chemistry." It is particularly gratifying to me, since I am to talk to you to-day on the subject of the organic constituents of soils, of their chemical nature and other properties, that Liebig is also known as the "Father of Organic Chemistry." To what tremendous proportions and significance in the world's industries and science this child of his (organic chemistry) has grown is familiar to all of you, and I assure you that Liebig, were he to return to-day, would be proud of its parentage. But I fear he would be displeased with his other child, as having made so little progress in the intervening years, although he started it in life strong and virile and full of promise. Up to a few years ago agriculture had not shared in the great impulses which modern science has given to other arts and industries, and the domination of the mineral requirement theory proposed in the first half of the last century and accepted without adequate proof of its validity is largely responsible for the lack of development in agriculture, commensurate with the enormous strides of other arts and industries under the guidance of modern scientific thought and research. But a new era of scientific inquiry is at hand and all phases of scientific endeavor are being applied to the solution of the problems connected with the soil's fertility and infertility—lines of scientific endeavor which were not even known to Liebig's time, but which to-day are well-recognized factors in soil fertility. I refer to soil bacteria, soil fungi, soil protozoa and other microorganisms, and all the biochemical functions of these, as well as of the higher plants, such as oxidation, reduction, enzymotic and catalytic, producing and destroying in the soil the organic constituents of which I shall speak presently. The soil is not simple, but complex. The soil properties and functions are likewise complex, not simple. All of the investigators preceding me in this symposium have emphasized to you by their papers how complex the subject is and how much remains to be done before a clear insight is obtained, but they have also shown to you clearly that a well-trained army of scientists is at work on the problems connected with soil fertility, applying thereto all the principles of modern science. The old view was simplicity itself; the soil was a mere trough in which the plant found its nourishment. But I can do no better than to let Liebig speak for himself. I quote from Letter XII. of his "Familiar Letters on Chemistry."

> A field in which we cultivate the same plant for several successive years becomes barren for that plant in a period varying with the nature of the soil; in one field it will be three, in another seven, in a third, twenty, in a fourth, a hundred years. One field bears wheat and no peas; another beans and turnips, but no tobacco; a third gives a plentiful crop of turnips, but will not bear clover. What is the reason that a field loses its fertility

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for one plant, the same which at first flourished there? What is the reason one kind of plant succeeds in a field where another fails?

Liebig answered these questions by saying:

> Wheat, clover, turnips, for example, each require certain elements from the soil; they will not flourish where the appropriate elements are absent. Science teaches us what elements are essential to every species of plant by an analysis of their ashes. If, therefore, a soil is found wanting in any of these elements, we discover at once the cause of its barrenness and its removal may now be readily accomplished.

But has science removed the causes of the barrenness of a soil by the analysis of the soil or of the ashes of the plants? In this connection it might be well to quote a statement from an article by Coleman, which was awarded the prize of the Royal Agricultural Society of England in 1855. The author says:

> The causes which operate in producing the fertility or barrenness of soils have hitherto to a great extent been shrouded in mystery, not from any want of study, but owing to the difficulties which meet the inquirer at every step and the fact that most important results frequently depend upon causes which have eluded the search of the experimenter. The science of chemistry it was hoped would afford the key wherewith to unlock the mysteries of nature, but though its discoveries have conferred much practical benefit on the agriculturist, it has up to a very recent period effected comparatively little toward settling the cause of fertility or sterility. The theories of scientific men led us to expect that fertility depended upon the presence of certain mineral substances which were found invariably present in the ashes of plants, and the analysis of the soil it was believed would confirm the practical experience of the farmer; these hopes have been falsified except in the few cases of almost simple soils, such as pure clays and sands. In all other cases the analysis presented the existence in varying proportions of these substances supposed to induce fertility in the barren as well as in the fertile soil. The proportion of the various ingredients was next proposed as a sign of quality, but researches into the amount of inorganic matter abstracted by each crop have demonstrated that soils of a mixed character contain abundant supplies of mineral food for numerous crops.

This was over fifty years ago, and the statements made are practically as true to-day as they were then. There has been a marked advance in agricultural practise, but until quite recently comparatively little light has been shed upon the scientific principles which underlie these practises.

In all justness to Liebig, however, rather than to his followers, I must make another quotation from his works to show that he himself recognized the insufficiency of the views expressed by the above quotations. He says:

> But it has been observed that the crops are not always abundant in proportion to the quantity of manure employed, even though it may have been of the most powerful kind; that the produce of many plants, for example, diminishes in spite of the apparent replacement by manures of the substances removed from the soil, when they are cultivated on the same field for several years in succession.

From the above quotation it may be seen that Liebig recognized that there are many cases which his theory of mineral requirement failed to cover. Indeed, if he had followed the idea embodied in the quotation to its logical analysis he would have reached some conclusions similar to those presented to you in the various papers to-day.

Even before, and especially since, the time of Liebig, much material of the kind presented to you by the preceding speaker has been accumulated and handled in the same statistical manner. I should here say that much valuable information has been thus obtained, but it should be needless for me to add that even with all these years of crop statistics at hand the difficult problems of the cause of fertility or infertility of our agricultural lands have not been thereby determined nor eliminated, as is again emphasized by what the other speakers have told you. The problem is not solved, though much progress has been made through the application of modern science. If the problem of soil fertility had been solved by the application of such statistics this symposium would not have been held. The pessimistic views expressed I can not share. Science is ever optimistic; the scientific investigator must above all things be optimistic and have an abiding faith that science will solve the intricate questions connected with his problem. The problem of soil fertility and infertility is broad enough and big enough for many workers and methods of attack. We can not all begin to unravel the tangled threads at the same point; there are different viewpoints and it is not improbable that some may have a keener vision than others to see the particular thread that will undo the snarl. The solution of the problem can only be reached through results of diligent experimentation, not by the statistics of even a hundred years. Criticism of the Bureau of Soils, similar to the present one, have recurred frequently in the past few years, as you are aware; but nevertheless the Bureau of Soils has continued its work from the new viewpoint and achieved some important results which throw much light upon the dark subject of the cause of fertility and infertility of our agricultural lands. I am very glad of this opportunity to present to you the results of a phase of this investigation, namely, the importance of the organic constituents of soils.

I have brought with me a tangible result of this work in the form of specimens of the organic compounds which have been found in soils. Their isolation and identification give definite information about a portion, and a very important portion, of the soil, the value of which has been recognized in practise, but about which no definite information was at hand, until this work was undertaken. By the application of modern methods of research to the intricate problems of the soil we have been able to throw such light upon the biochemical changes in soils that the old views of soil organic matter, soil humus and the process of humification are entirely overthrown. The compounds of which Mulder, the contemporary of Liebig, writes, such as humic acid, geic acid, ulmic acid, etc., terms which have appeared in text-books ever since, have absolutely no existence, but are shown to be mixtures of many different, and widely different, compounds. Not only were the compounds contained in these specimen tubes not known as soil constituents to Mulder or Liebig, but they were unknown to science at that time. With the advance of science since that time, especially of biochemistry, results such as these have been made possible. Some of these compounds contain only carbon and hydrogen; some, carbon, hydrogen and oxygen; some, carbon, hydrogen, oxygen and nitrogen; and some, carbon, hydrogen, oxygen, nitrogen, and phosphorus. The compounds represent a great variety of chemical classes; there are paraffin hydrocarbons, hydroxyfatty acids and other organic acids, esters and alcohols, carbohydrates, hexone bases, pyrimidine derivatives, purine bases and pyridine derivatives. The individual compounds isolated or found are as follows:

ORGANIC COMPOUNDS ISOLATED AND IDENTIFIED

Hentriacontane,	Phytosterol,
Paraffinic acid,	Liquid glycerides,
Lignoceric acid,	Picoline carboxylic acid,
Agroceric acid,	Nucleic acid,
Monohydroxystearic acid,	Cytosine,
Dihydroxystearic acid,	Xanthine,
Resin,	Hypoxanthine,
Resin acids,	Adenine,
Resin esters,	Histidine,
Pentosan,	Arginine,

Pentose,	Choline,
Agrosterol,	Creatinine.

In addition to those here mentioned, a number of others are already isolated and will soon be reported. It is obvious that definite chemical information of this kind sheds much light upon the nature of soil organic matter and the processes going on in the soils. The compounds encountered are the same as those encountered in other lines of biochemistry and, therefore, the knowledge in regard to chemical relationships, origin and processes of change accumulated in such other lines can be directly applied to the understanding of the biochemical changes in soils and the constitution of soil organic matter. It is not my purpose to discuss the biochemical changes here other than to say, in passing, that the occurrence of these products which have an obvious chemical relationship with the great classes of tissue material contained in the plant and animal débris that gets into the soil, the carbohydrates, the fats, the proteins, the nucleic acids, the lecithins, etc., proves conclusively that the process of humification is not a mysterious process which takes place in soils only and can not be understood, but rather that the process of change in the soil is, after all, very closely paralleled by the processes known to take place in the laboratory when the complex organic substances are split by hydrolysis, oxidation, reduction or deamidization, into simpler derivatives. It is my purpose, however, to bring strongly before you the fact that these soil constituents affect plants directly.

As scientists personally interested in all that has to do with plant life and development, you will be glad to learn that we have studied as many as possible of these compounds in such a way as to determine what their possible function in the soil may be. Indeed, the reason why this investigation of the organic matter in soils was undertaken is to be found in the fact that certain soils and soil extracts behaved toward plants as if they contained something detrimental to crops rather than an absence or deficiency of the usual beneficial elements like nitrogen, phosphorus or potassium. This harmful effect on plant growth can be shown very readily by any one with such a soil under investigation. The soil is shaken with distilled water for several minutes, allowed to settle, and the supernatant liquid filtered off, which must usually be done with a Pasteur-Chamberland filter in an apparatus specially designed for such work, in order that all solid material may be removed. The clear filtrate is then used as a medium for the growth of wheat seedlings in bottle cultures. A control in pure distilled water, or in an extract from a fertile soil, should be run at the same time. In such cases the plants grown in the extract from the poor soil will show many peculiarities not shown by the plants either in the pure distilled water or in the extract from the good soil. The plant will be smaller, less developed in top and root, the latter often showing dark and swollen tips, which are sometimes bent into hooks, a phenomenon characteristic of certain toxic action. The growth in this soil extract may even be greatly less than the growth in the distilled water, although the soil extract naturally contains plant nutrients, whereas the distilled water contains none.

If a separate portion of the original extract be treated with carbon black, made from natural gas by imperfect combustion much as lampblack is formed on lamp chimneys, agitated and filtered, the filtrate will be a good medium for the growth of the seedlings. This simple treatment with carbon black has, therefore, removed by absorption the harmful properties of the soil extract and the growth is now even better than in the distilled water.

Another experiment with soil and carbon black was made as follows: A layer of moist carbon black was covered with a layer of moist unproductive soil and this in turn by a layer of moist carbon black. In this experiment the moisture could circulate from the soil to the carbon black and back again and thus gradually the soil fluid would be freed of any injurious compounds by absorption into the carbon black. At the end of a day or two of this interaction the soil was freed from the carbon layers, plants were grown in it, and when compared with soil not so treated a very marked improvement was shown, again indicating that a harmful body was originally present and had been removed in whole or in part by this carbon black treatment.

Observations of this kind on many soils, together with a study of the properties of the material dissolved in the water, led to no definite isolation of the compound or compounds showing the harmful effect, owing to the fact that the quantities in the water extract are too small for identification, but they did lead to a recognition that the substances were not mineral in character, but were constituents of the organic matter of the soils.

That organic substances could produce such effects in such small quantities as must be present in soil solutions was not apparent from the literature and it became necessary to establish this point. With this in view, a test of about forty substances of organic origin which may get into the soil or be formed therein were tested, and it was conclusively shown that a number of these were decidedly harmful to plants, even in very dilute solutions comparable with the organic content of soil solutions.

It therefore became essential to make a study of the organic matter of the soil. The organic matter of the soil, however, was a subject about which the older chemistry of agriculture had much to say, but in regard to which modern science was discreetly silent. With no established facts and no methods of attack worked out, progress was necessarily slow at first, but gained speed with each compound isolated or identified until to-day there have been isolated in these laboratories more than twenty-five definite compounds from soil organic matter and the work is progressing at a rapid pace.

The search for this supposedly harmful constituent was rewarded by the discovery, among others, of dihydroxystearic acid, a compound which, on account of its frequent occurrence in soils, has been rather thoroughly studied in regard to its effect on plant development and growth.

The isolated and purified dihydroxystearic acid was tested by dissolving it in pure distilled water and it was found to have decided deleterious action on the wheat seedlings used in the tests. The acid prepared in the laboratory behaved in the same manner.

Its effect in the presence of nutrient salts was also extensively studied in solutions containing calcium acid phosphate, sodium nitrate and potassium sulphate, alone and in combinations of two and three of these salts, a total of sixty-six cultures being used in a single test. The injurious effect of the dihydroxystearic acid was less where all three of the nutrient elements were present than where only one or two were present. The injurious effect was least in those cultures of three nutrients where the nitrate was high. This indicates that the action of the nitrate tends especially to overcome the harmful effect of the compound or else it enables the plant to resist or overcome its effect.

Dihydroxystearic acid has another effect which should here be mentioned as having a considerable bearing on its effect on crops, even in such soils as contain much plant nutrient material in the most readily available form. This is its influence on the absorptive power of the roots of the plants growing in the soil, the soil solution, or solutions of nutrient salts when dihydroxystearic acid is present in them. The absorption of potassium and phosphate was greatly interfered with, although both were present in soluble form in the culture solutions; only the nitrate was consumed in any quantity. This is in harmony with the fact stated above that when nitrates were plentiful in the solutions, the best growth was obtained and the effect of the harmful compound was minimized or entirely overcome.

The occurrence of dihydroxystearic acid was specifically studied. For this purpose soil samples of good and poor fields were collected and examined for this constituent. Soils from eighteen different states, extending from Maine to Oregon, and southward to Texas, of widely different origin, topography, texture, climate, drainage and cropping, varying from soils of the highest productivity to soils incapable of producing profitable crops, were examined for dihydroxystearic acid.

One third of all the soils examined showed the presence of this compound. It was found in virgin soils as well as in soils under long cultivation; in soils continually cropped as well as in soils under permanent sod; in soils from the Atlantic coast; in soils from the Pacific coast; and in soils from the gulf states. This compound is, therefore, a common soil constituent and is likely to be encountered in soils anywhere. Its formation or its accumulation is doubtless due to local conditions in any one section, but those local soil conditions are not confined to any region of the United States and probably not to any country or continent.

When the soils examined are separated into good and poor soils, as based on field observations, their relationship with dihydroxystearic acid is rather striking. Among the good soils only two contained dihydroxystearic acid and they were of only moderate productivity. Among the poor soils the number of those containing this compound was approximately one half. Of the soils which had a definite record for infertility, the dihydroxystearic acid was found in each and every case.

Judging from the foregoing relationships established by this investigation it would seem that dihydroxystearic acid is either a direct or indirect factor in the low productivity in soils; direct by virtue of its harmful effects on growing crops, indirect as an indicator of other compounds or conditions which cause soil to become less productive and even infertile. It is not possible to state from the data at hand that dihydroxystearic acid is the only factor which contributes to the infertility or unproductivity in those soils in which it was found, for it must be remembered that this is only one of many compounds, both organic and inorganic, harmful and beneficial, as I shall show presently, which exist in soils, any and all of which play a part in its relative fertility and infertility. It is certain, however, that the determination of even this one constituent leads to a recognition of the kind of infertility in the soils examined and is, therefore, a readily recognized symptomatic factor of poor soil conditions.

The isolation of harmful constituents is, however, only a part of the entire field covered by these investigations into the nature and properties of soil organic matter, and I am very glad to be able to announce to you the existence in the soil of organic compounds decidedly beneficial to plant growth. Here is, for instance, a specimen of creatinine, a nitrogenous compound, which we have isolated from soils. This compound has always been associated with animal material, but in addition to finding it in soils we have also found it to exist in many plant materials, for instance, in wheat seeds, wheat seedlings, wheat bran, in rye, clover, alfalfa, cowpeas and potatoes, and if, as is suggested by several investigators, creatinine in the animal arises as the result of the breaking up of albumen, then it seems reasonable to expect that creatinine would be found in practically all plants. From the standpoint of root excretion I should also mention the fact that of samples of the same soil planted and unplanted, the planted soils give larger amounts of creatinine, thus showing that the increase of creatinine in the soil is connected in some way with plant growth. When the roots of wheat were bathed in water the creatinine could also be found in the culture water. One of the sources of creatinine in soils would, therefore, seem to be found in the presence of this compound in plants, since by the decay of plants and by direct sloughing or even by excretion, the creatinine is left in water and soil. Its occurrence in stable manure and also in green manures is another source, and its formation by soil organisms may be another. Whatever its source, it occurs in soils, and appears to be a normal and frequently occurring constituent and is present in amounts comparable with the amounts of soil nitrates found in ordinary agricultural soils. Its effect on plants, as I have implied earlier, is decidedly beneficial. When a series of cultures containing only potash and phosphates in varying proportions is set up together with another set containing in addition some fifty parts per million of the creatinine, the increased growth in the latter set is rather striking, fully comparable with the increased growth produced by nitrates under the same circumstances. When nitrates are present at the same time, the additional effect of the creatinine is not so marked, but an analysis of the culture solution reveals the fact that far less nitrates are used by the plants in the presence of the creatinine, although a larger plant growth takes place. In other words, the plants absorb the creatinine, make use of it in building up tissue, and in so doing a diminished draft is made on the supply of nitrates. It appears, therefore, that this soil constituent is fully as valuable as soil nitrate, can be present in amounts comparable to the amount of nitrate in soils and is able to replace the latter in its effect on plant growth. The significance of this to agricultural investigations is apparent.

Nor is creatinine the only constituent that behaves in this manner. The same beneficial characters are shown by other soil constituents, by the hypoxanthine and xanthine, by arginine and histidine and by nucleic acid. All these show the same beneficial character on plant growth and the same effect on the decreased nitrate consumption. Based on the results of these rather extensive investigations, I am ready to formulate the theory that these degradation products of protein are absorbed directly by the plant from the soil and that the plant uses these units for building up the complex proteins as far as it is possible to do so. Nitrate is usually considered as the best form of nitrogen for plant food. In order to use nitrate, a highly oxidized form of nitrogen, to form the amido and imido groups of the protein molecules, a reduction must take place.

It is obvious that the plant must spend considerable energy in making this transformation. What is more reasonable than to suppose that the unit parts of the complex protein molecules, when presented to the plant, will be used by it in preference to expending labor on the nitrate to prepare these units? If a soil be liberally supplied with all of these units, it is conceivable that good plant growth will result, even without nitrate. If only a limited amount or kind of the units be present, the plant must have nitrates with which to supply the missing units. The knowledge, therefore, that such compounds exist in soils and play such a prominent part in the metabolism of the growing plant is of fundamental significance in soil fertility and gives a breadth of view to the subject which in its horizon can not be compared with the restricted vision imposed by the purely mineral requirement theory of Liebig, as this is used by his followers.

Nitrates are not produced in these cultures. Ammonia if formed is insignificant in amount, nor does ammonia produce the striking results shown by these organic compounds. There is a limit to the amount of any one of these soil constituents which the plant can profitably use and show increased growth. When a mixture of several of these units is presented at once, the growth is better than if an equivalent or even larger amount of any single one is presented.

These compounds are nitrogenous, but it must not be inferred that all nitrogenous compounds are beneficial to plant growth. Tyrosine, also a degradation product of protein, is distinctly harmful, and picoline carboxylic acid, isolated from soils, is moderately toxic. Guanidine, a compound not yet isolated from soils but whose presence is indicated, has also been rather thoroughly studied, and is decidedly harmful to plants, producing an effect on the cultures similar to that shown by certain plant diseases. The leaves become spotted with bleached dots, which spread and ultimately coalesce, producing a wilting of the plant and finally death. Not only is the guanidine harmful, in contradistinction to the beneficial nitrogenous substances just discussed, but it also differs from these compounds in its behavior when nitrates are present. The latter fertilizer ingredient very greatly increases the toxic action of this compound. This is especially striking when a large series of cultures with and without guanidine in the presence of many ratios of phosphate, potash and nitrate is set up and the cultures arranged according to the nitrate content. Both groups of cultures with and without guanidine will grow nicely for three or four days without any peculiarity being noticeable in either group. The cultures high in nitrates will be the first to show the symptoms of guanidine poisoning, and this effect will spread through the guanidine group of cultures, becoming more and more marked in those high in nitrates. At the conclusion of two weeks the group of cultures containing no guanidine will appear green and fresh, whereas the guanidine group appears bleached and wilted in all of the cultures containing nitrates. The cultures which contain no nitrate, that is, only potash and phosphate, are the only cultures which have been able to withstand the ravages of this poisonous compound. We have here a striking illustration not only of the harmful effect of an organic nitrogenous compound, but also an example of the increased harmful effect brought about by the addition of the otherwise so beneficial nitrate. This is in strong contrast to the ameliorating effect of nitrates over all other fertilizers in the case of the harmful soil constituent, dihydroxystearic acid. Guanidine is harmful and dihydroxystearic acid is harmful, although this manifests itself in a different way. Nitrate increases the harmfulness of guanidine, but decreases the harmfulness of dihydroxystearic acid. Here is an effect of a fertilizer which is entirely unexplainable from the viewpoint of mineral requirement or plant-food addition.

Nor is this behavior of nitrate in influencing the effect of these organic substances on plant growth and development the only illustration of the influence that different fertilizer salts can exert on the action of the organic compounds on plants. Cumarin is another substance which we have studied quite thoroughly in its effect on wheat seedlings. Besides decreasing growth, it also has a very peculiar and characteristic action on plants which enables the experimenter to pick out cumarin-affected plants at a glance from those affected by any other toxic body studied by us. The leaves are shorter and broader than is normal for wheat and only the first leaves are usually unfolded, the other leaves remaining wholly or partially within the swollen sheath. Such leaves as do break forth are usually distorted and curled or twisted. Now when cumarin is contained in the culture solutions of the various fertilizer salts, it is quite apparent that neither nitrate or potash nor combinations of these affect these characteristic symptoms of cumarin poisoning, but the slightest addition of phosphate causes a very decided change in the appearance of the plants, which increases with increasing phosphate until nearly normal development is obtained, as shown by comparison with the corresponding cultures without cumarin.

I must also cite to you the influence of quinone when similarly studied. The effect of quinone is decidedly different from the effect of cumarin, which produced short, broad, irregularly developed leaves and stunted tops; the effect of quinone is to produce long thin leaves, and tall slender plants. The interesting part in this connection, however, lies in the fact that the growth in the cultures high in potash was nearer to the normal than the growth in either the mainly phosphatic or mainly nitrogenous cultures, and was in fact poorest in the latter. Vanillin similarly studied behaved like the dihydroxystearic acid in that nitrates were the most efficient aid to counteract its harmful effect on plants.

These experimental facts present much interesting material for discussion from various points of view, but I wish here only to call your attention to the relations between organic compounds, their effect on plants, and the action of fertilizers in this connection, which action is apparently apart and in addition to any food value of the fertilizer salts for plants in the usually accepted sense. It is clear that in the illustrations which I have here given you, the various fertilizer salts acted differently in overcoming the respective harmful effects of these toxic organic compounds. The mainly phosphatic fertilizers were the most efficient in overcoming cumarin effects; the mainly potassic in overcoming the quinone effects; the mainly nitrogenous fertilizers in overcoming the vanillin and dihydroxystearic acid effects; and in the case of guanidine, the mainly nitrogenous fertilizers even had the effect of increasing the harmfulness of this compound. It is clear that the organic compounds in soils, whether already isolated and studied or yet to be found, are potent factors in soil fertility as they have a direct effect on plant growth and plant metabolism and on the action of fertilizers. These actions of the different fertilizer combinations or different fertilizer requirements, as they may be styled, show a certain parallelism with field observations on soils and their fertilizer requirements, and one is tempted to ask to what extent the different fertilizer requirements of different soils, or of the same soil under different conditions, may be influenced by the same cause. That harmful bodies occur in soils has been amply shown and that these are influenced directly or indirectly by fertilizer salts is also clear from these and other researches. That the constitution of the organic matter varies from soil to soil and in the same soil under different conditions of aeration, drainage and cropping is likewise clear. The presence of compounds inimical to plant growth by virtue of a property resembling that of any of the above-mentioned substances might, therefore, cause a different fertilizer requirement, a requirement which might even change from time to time, according to the nature of the biochemical relations producing the body or according to the nature of the plant remains in the soil; in other words, according to the rotation, with its necessarily altered soil management, and the altered biochemical changes produced in the different plant remains.

The soil has vital functions. The soil can not be considered as the dead, inert remains of rocks and previous vegetation, but must be considered as an accumulation of such material in which the process of formation, alteration and transposition are still at work. In other words, the soil in its entirety is not dead or inert, but endowed with functions analogous to those of life itself. In it take place the same processes of solution and deposition that have taken place in past ages, and are taking place to-day in the geologic processes connected with the action of the water on the rocks and minerals of the earth's crust. In it take place the same physical and chemical interactions as take place in the movement of subsurface waters generally, resulting in ore formations or depositions. In it take place the same processes of fermentation, digestion, or decay of organic materials as take place in animals and plants or in the production of industrial products, such as cheeses, wines and beers, brought about in the soil as in these other processes by means of ferments, enzymes, bacteria and fungi or molds. In it take place the same processes of oxidation and reduction which play so enormous a part in all life processes, and these researches have shown the nature of compounds in the soil organic matter to be the same as those derived from such life processes or from similar laboratory processes of digestion, oxidation or reduction. Organic matter is very changeable; it is the material which forms the food, as it were, of all the microorganisms of the soil, of the bacteria, of the molds, of the protozoa, and influences them favorably or unfavorably, just as the higher plants are affected. In turn these agents are great promoters of these changes in the organic débris of soil. All of these processes and the life forms in the soil are affected by fertilizer salts when added to the soil, and changes are produced in the soil, physical, chemical and biochemical, which influence the soil and affect its potential fertility entirely irrespective of the added plant food. In other words, the soil has been changed in many prominent characteristics even before any crop is planted therein.

I must not leave this subject of fertilizer action, in view of the preceding paper, without saying that the Bureau of Soils takes an advanced stand not only on the present use of fertilizers, but on their extension in agriculture, in spite of the reiterated statements to the contrary. The point of difference lies in the explanation of their action, the one view being that they are merely so much plant food which must replace the removal by crops, the other being that in addition to any plant food value which they possess, they affect the soil and produce changes and influences such as are at least partially illustrated by the experimental results cited here. We believe that these additional—note particularly that I say additional—actions explain more fully the function of fertilizers in agriculture. From the former view the application of fertilizers would be restricted to poor and so-called exhausted soils and poor systems of agriculture; from the latter viewpoint, fertilizers are indicated as well for fertile as for infertile soils, as an adjunct to successful farming and bringing the soil to its highest capacity of crop production.

The action of fertilizers on soils is a much contested question, but the weight of evidence is against the assumption that their effect is due altogether to the increase of plant food as such. If so simple an explanation were the true one, nearly a century of investigation of this problem by scientists of all civilized nations would surely have produced greater unanimity of opinion than now exists in regard to fertilizer practise. Thoughtful investigators everywhere are finding that fertilizer salts are influencing many factors which contribute toward plant production besides the direct nutrient factor for the plant. It is this additional influence of fertilizers which makes them doubly effective when rightly used and inefficient when improperly used. To this influence of fertilizers on soil and biological conditions is due their capriciousness when applied on the theory of lacking plant food, and any study which throws further light upon the mooted question is of direct help toward reaching that view of soil fertility and soil fertilization which will eventually result in a more definite, more rational and more remunerative fertilizer practise than in the past, and thus bring about the more extensive use of fertilizers in agriculture.

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THE DRIFT IN SECONDARY EDUCATION

IN the course of a preliminary study of the conditions affecting a particular high-school subject, I have been led to glean from the reports of the Commissioner of Education data which, tabulated or represented graphically, may have a certain interest.

The table has to do with the expansion of secondary education, 1890–1910. It is self-explanatory, but one or two points in it may be noted. First, while the population of the continental United States has increased 50 per cent. the proportion of the population in the secondary schools has been multiplied by about *three*. Second, that while the proportion of students completing the secondary course and graduating has slightly but decidedly increased, the proportion of them preparing for college, either classical or scientific courses, has been diminished by about 60 per cent. Third, that the proportion of boys in the secondary schools has in twenty years not varied much from 44 per cent.; also, that the proportion of boys in the successive years falls off somewhat, but not as largely as I had been supposing; in fact, the "elimination" of girls goes on at almost as rapid a rate as that of boys. Finally, that while the amelioration of conditions as shown by the number of students per teacher is noticeable, the burden placed upon the teacher in small high schools is in this respect markedly less than in those in cities of 8,000 inhabitants or more, and in these small schools the improvement is much greater. Of course, specialization in teaching tends in some degree to counteract this.