

Organic Manures and Plant Nutrition.

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THE importance of organic manures in agricultural practice has been recognised from the earliest times. In ancient China, as also, to some extent, in Aryan India, the utilisation of different forms of organic waste materials as manures was regarded as an important item of field operation. In the early days, as also in the centuries that followed, it was believed that the plant derives the bulk of its food from pulverised soil and manure together with water. The importance of cultivation was therefore greatly stressed upon and farmers ploughed their lands to bring it to a consistency suitable for direct intake of soil materials by the plant.

The discovery of the fertilising value of nitre and various other mineral salts, as also the increasing evidence to show that the plant derives the bulk of its organic material from the carbon dioxide of the atmosphere, brought about a rapid change in scientific opinion regarding plant nutrition by about the middle of the last century. The later exponents of agricultural science naturally argued that the plant depends on soil only for its supply of water and mineral salts and that the application of bulky organic manures is not only expensive but also quite unnecessary.

Many practical farmers, particularly those of the older generation, did not, however, accept the new theory of plant nutrition. They continued to believe in the efficacy of farmyard manure and would not use the new mineral fertilisers except in small doses and that in combination with organic manures. Their cautiousness did not meet with the sympathy of the younger generation, but subsequent experience has justified the wisdom of such a policy. (1) Mineral fertilisers are not consistent in their action. In favourable seasons they are as good as or even better than organic manures, but in seasons of drought or excessive rainfall they have often proved highly disappointing. (2) Soils continuously treated with the same mineral fertilisers become increasingly acid or alkaline in reaction. The average yields from such areas tend to steadily diminish

with time as compared with those of similar soils treated with organic manures. The observations on the permanent manurial plots at Rothamsted, Woburn and elsewhere lend strong support to this statement. (3) In horticultural practice, exclusive use of mineral fertilisers has, generally, proved unsatisfactory. Not only the yield but also the quality of produce is often reported to have suffered as the result of substitution of organic manures by mineral fertilisers. (4) In tropical countries, where soils are naturally deficient in organic matter, the response from exclusive use of mineral fertilisers has not generally been satisfactory. In many places, depressed yields, almost amounting to complete failure of crops, have been reported as the result of heavy applications of minerals in quantities corresponding to those adopted in European countries. (5) In recent years, a number of workers—among whom particular mention should be made of McCarrison and his co-workers at Coonoor and Viswanath and his associates at Coimbatore—have obtained evidence to show that grain and fodder crops raised on mineral fertilisers are comparatively less nutritious or otherwise poorer in quality than those raised on organic manures. The above and related observations have naturally led to the conclusion that organic manures play a more important part in plant nutrition than that of merely conserving moisture in the soil and reducing resistance to the plough as has so far been believed.

A careful analysis of the different possible ways in which organic manures can assist plant nutrition would suggest the following: (1) They may decompose in the soil releasing minute quantities of certain rare minerals which are essential to plant growth but are not provided by any of the known combinations of mineral fertilisers. (2) Some of the organic constituents of the manures themselves or the products of their decomposition in the soil may be directly assimilated by plants with beneficial results. (3) The decomposition of organic manures in soils may be accompanied by profuse evolution of carbon dioxide which would be

assimilated by plants growing thereon, thereby yielding heavier crops than would otherwise be possible.

With reference to the first suggestion, it may be mentioned that most organic manures are essentially of plant origin, so that the prospect of their containing rare minerals not ordinarily present in the soil is rather remote. It is also known that the main mineral requirements of plants are confined to a few well-known groups, while the others are required in such small quantities that most soils in the world may be said to contain sufficient quantities to meet the most exorbitant demands of crops, almost indefinitely.

Direct experimental evidence on this aspect of the problem has not, however, so far been adequate. A number of experiments were therefore carried out by the authors, adding varying quantities of the mineral residues of different organic manures, both by themselves and in combination with other minerals, to acid-washed sand and studying the effect thereof on plant growth. The experiments were carried out with a variety of plants and in different seasons: they were also repeated on a number of soils. As the result of a large number of observations, thus made, it is now possible to state, conclusively, that the commoner types of organic manures do not contain any rare forms of mineral matter that are essential to plant growth. The following observations which relate to one set of experiments would illustrate the above statement:—

Barley raised on	Average dry weight of seedling in mg.
Sand + Complete minerals ..	42.6 ± 1.7
„ + „ + Ash of farm-yard manure (by ignition)	36.8 ± 1.2
„ + „ + Mineral residues of farm-yard manure (after repeated treatment with hydrogen peroxide) ..	37.5 ± 1.6

As already mentioned, the idea of organic manures or their products of decomposition serving as direct nutrients to plants dates back to the earliest times, though experimental evidence on this aspect of the problem is still inadequate. Particular

mention should be made of the work of Wildier who noticed that yeasts do not flourish except in presence of an organic substance, 'Bios', present in beer wort, yeast water and such like media; of Bottomley and Mockeridge, who observed that growth of certain aquatic plants is not possible except in presence of certain substances, the 'Auximones', which are present in organic manures. Later researches, by a number of workers, have not entirely supported the observations of Wildier and Bottomley. The practical significance of such findings, in relation to field practice, is still not clear.

With a view to obtaining some direct evidence on this aspect of the problem, a number of experiments were carried out by the authors with pot-cultured plants. In one set of experiments, a number of organic substances were added to acid-washed sand, both by themselves and in combination with different mineral salts, and the effect thereof on plant growth studied. The experiments were repeated in different seasons and with various species of plants. In another series of trials, aqueous extracts of different organic substances were injected directly into the plant system and the effect thereof on growth and reproduction determined. The injections were also repeated at various stages of plant growth and in different seasons.

The observations on sand-cultured plants have shown that (a) even under carefully controlled conditions it is not possible to prevent the action of micro-organisms on the added organic substances, and (b) the effect produced by minute quantities of different organic substances, at any rate in the earlier stages of plant life, is indistinguishable from that produced by mineral fertilisers applied together with them. The following table presenting one set of observations would illustrate the position:—

Barley raised on	Average dry weight of seedling in mg.
Sand (1.5 kg.) + Complete minerals ..	27.4 ± 0.8
„ + „ + Dried blood (0.05 g.)	26.4 ± 0.4
„ + „ + Aqueous extract of dried blood (0.05 g.)	27.7 ± 1.0

The injection experiments were first carried out with the sun flower plant (*Helianthus annuus* Linn.) and then extended to

other species. The observations showed that aqueous extracts produce no appreciable effect on plant growth. Repetition of the experiments on comparatively mature plants showed, however, that minute quantities of certain substances produce an entirely different, but no less important, effect by increasing the proportion of flower and seed to the whole plant as illustrated by the following results:—

Fluid injected	Percentage (weight) of flower to the whole plant in mg.
Yeast extract	24.4
Farmyard manure extract	24.8
Soil extract	21.7
Distilled water (control)	13.1

The foregoing observations are of considerable practical importance and are now being extended to a large number of agricultural as well as horticultural plants with a view to (a) determining the nature of the constituents responsible for the effects observed and the mechanism of their action, and (b) devising methods of extending the treatments to field practice. The effects of injecting a number of new substances are also being studied. A number of new methods of direct feeding are also being tried.

There is evidence to show that (1) the carbon dioxide content of the air above a soil treated with organic manure is generally higher than that above a similar area which is either left unmanured or treated with minerals, and (2) when a soil is under vegetation, the carbon dioxide content of the strata of air below the leaves is higher than that above them. These observations combined with the fact that, other conditions being alike, photosynthetic assimilation is proportional to the concentration of carbon dioxide in the air, would suggest that the beneficial effect of organic manures is at least partly due to the enrichment of the atmosphere with that gas. On the other hand, it may be argued that, being a gas, carbon dioxide would get readily disseminated in the atmosphere so that plants raised on mineral fertilisers would receive about the same supply of that gas as those grown on organic manures. Moreover, it should be admitted that artificial enrichment of the atmosphere with carbon dioxide does not always lead to

increased crop yield: in fact, the exhaustive researches carried out in Germany and elsewhere would show that many of the crops do not respond favourably to that treatment. As further arguments against the theory, it may be pointed out that (1) no experimental evidence has, so far, been obtained to show that plants can flourish in the absence of atmospheric carbon dioxide while it can be demonstrated by water and sand culture experiments that they can live and grow independent of organic manures, and (2) the quantitative carbon relations between the soil, the plant and the atmosphere have not been defined so that it is not possible to state as to what extent the increased production of carbon dioxide in a soil is due to the oxidation of the organic manure alone.

A critical analysis of the literature on this aspect of the problem would, however, reveal that (a) although plants can be raised in the absence of organic matter, yet the growths thus obtained are rarely ever so satisfactory as those on soils, particularly those which are naturally rich in organic matter or receive good dressings of organic manures, and (b) the previous workers who sought to increase crop yield by artificially enriching the atmosphere with carbon dioxide did not take the aeration of roots into consideration. There are very few plants in nature which can flourish without adequate root aeration, so that abnormal increase in the concentration of carbon dioxide around the plant would naturally reduce the supply of oxygen to the roots, which would, in consequence, suffer. The availability of carbon dioxide from organic manures would, on the other hand, be largely determined by oxidation changes in the soil which, in turn, are dependent on soil aeration, so that the two essential conditions, namely, adequate supply of oxygen to the roots and increased concentration of carbon dioxide around the leaves would both be satisfied at the same time. It may be concluded, therefore, that the evidence on this aspect of the problem is still incomplete and that further work is needed to define the nature of the relation between the decomposition of organic matter in the soil and photosynthetic assimilation of carbon dioxide.

With a view to throwing some fresh light on the above and related questions, a number of experiments were carried out, adding

organic manures to different soils and studying the attendant transformations, with special reference to the production of carbon dioxide and plant assimilation. The results may be summarised as follows:—(1) In the study of oxidation changes not only the added manure but also the organic matter already present in the soil should be taken into consideration. The latter is not only very much larger in quantity but its decomposition is also vastly more important than that of the former. Various factors such as seasonal changes, cultivation operations, application of different fertilisers and the nature of the vegetation determine the release of plant food from the organic reserves of the soil. (2) Plant growth is possible, at any rate in the early stages, in the absence of atmospheric carbon dioxide. Barley seedlings grown on manured soil show a definite gain in dry weight when air freed from carbon dioxide is drawn over them. No significant difference in weight could be noticed between seedlings grown in ordinary air and those over which CO_2 -free air had been drawn, so that it would appear that the bulk of the carbon dioxide assimilated by the plants actually came through decomposition of organic matter in the soil. The following results would illustrate the above:—

Plant growth in the absence of atmospheric carbon dioxide.

Barley grown in	Average dry weight of seedling in mg.
Open air (Control)	.. 33.3 ± 0.8
Glass chambers (ordinary air drawn through)	32.7 ± 1.6
Glass chamber (CO_2 -free air drawn through)	.. 33.2 ± 3.5

In view of the evidence to suggest that the oxidation of the organic reserves of the soil is of considerable importance in plant nutrition, a number of experiments were carried out to study the effect of various treatments calculated to assist oxidation changes in the soil. The results showed that not only aeration but also treatments with different oxidising agents are greatly helpful in promoting plant growth. The following observations relating to a poor, gravelly soil containing 0.8 per cent. of organic matter will be of interest:—

Effect of treatment with oxidising agents on plant growth:—

Treatment	Average weight of barley seedling in mg.
Soil alone (Control)	.. 38.2 ± 4.2
„ + Ferric oxide (3 g.)	.. 51.2 ± 3.1
„ + Potassium permanganate (0.075g.)	.. 53.6 ± 1.7
„ + Hydrogen peroxide (1 c.c. of 3 per cent. soln.)	.. 49.8 ± 3.1

The foregoing observations are of much practical significance. Even the poorest soils of the world contain sufficient reserves of plant nutrients to meet the heaviest demands of crops for several decades, though under ordinary conditions, they are mostly unavailable. Judicious field practice will therefore have to include a system of utilising such reserves of the soil, together with the added manures, to the best advantage of the growing crop. At the same time, profuse decomposition should be avoided as it would result in rapid depletion of the organic reserves without adequate crop return. The oxidation changes should be hastened just at the time when crops require them most and, if possible, retarded at others.

The mechanism of the action of oxidising agents is still obscure. Whether those chemicals react directly with the organic matter forming carbon dioxide and other plant nutrients or merely bring about partial oxidation rendering the materials suitable for microbial action is still to be determined.

The ultimate processes leading to the conversion of organic manures into plant food are not yet fully understood. Particular mention should be made of the large quantities of organic as well as mineral matter stored in microbial cells and the subsequent release of which greatly adds to the fertility of soil. The mechanism of such transformations and the extent to which they are affected by different soil treatments are still obscure.

A further aspect of the problem which requires elucidation is the mechanism of oxidation of organic matter in swamp soils. Although it is now well established that the initial transformations attendant on the application of organic manures, particularly green manures, are of the nature of acid and gas fermentations, yet the subsequent changes leading to the conversion of these products into plant food are not yet fully understood. It is hoped that later researches will throw some light on the above and related problems.