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SOIL FERTILITY AND DISEASE RESISTANCE

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I. *INTRODUCTION*

THE farmers of the Occident and the cultivators of the Orient look upon the maintenance of soil fertility from two very different points of view.

In this country, for example, where the Liebig tradition and the ideas underlying the old Rothamsted experiments still hold sway, the majority of the farmers and many of the experiment station workers are apt to envisage soil fertility as a matter primarily involving the composition of the soil solution and its replenishment by means of artificial manures. The problem is considered to be a twofold one: the purchase of so many pounds of nitrogen, phosphate and potash per acre in the cheapest market, followed by the proper admixture of the constituents. We read a great deal nowadays of the merits of balanced manuring and of the need for its timely application. Clearly the secret of success is considered to lie in the discovery of the ideal prescription.

The soil solution, however, is only one of the factors concerned in soil fertility. This is evident when we consider the manner in which the plant and the soil come into gear by means of the root-hairs and the pore-spaces. It is at once apparent that the internal surface of the soil—known collectively as the pore-space—and its well-being are the things which really matter. What is important to the green plant is not the acres of the farmer, but the much larger acreage of the pore-space, its moisture and oxygen content and its teeming microscopic population, some of whose by-products become dissolved in the soil solution. The pore-space and its activities are the centre of the subject. The first thing to do therefore is to maintain and if possible to expand the internal soil surface so that the maximum area is available for the root-hairs. After this the needs of the soil population and of the root-hairs for such things as oxygen, water and other food materials must be considered together and not as unrelated fragments. The problem of maintaining fertility widens: the inadequacy of the Liebig tradition becomes apparent: the ideal prescription does not suffice.

When we analyse the practice of the best cultivators of the Orient, a different approach to the soil fertility problem discloses itself. Questions of balanced manuring do not arise as artificials are either unknown or are unprocurable. The peasants of China, for example, consider first and foremost the needs of the soil population in the shape of a continuous supply of fermented organic matter (humus) by which these organisms are provided with energy. The greatest care is taken to prepare this humus on correct biochemical principles in a finely divided condition so that when this material is worked into the soil as many as possible of the pore-spaces are provided with a minute fragment of organic matter ready for nitrification. Every possible kind of waste—animal, vegetable and human—is carefully collected and converted into humus. The Chinaman feeds his soil population and allows the soil solution to take care of itself. For forty centuries his system has been in operation: an enormous number of human beings have been maintained on the land and fed from the products of the country-side: there has been no wearing out of the soil and no falling off in fertility: the system has stood the test of time without the least sign of breaking down.[1]

The contrast in the method of approach to the soil fertility problem by the West and by the East can be summed up in a few words. The farmers of the Occident are striving to maintain crop production by means of dope: the cultivators of the Orient by means of diet. The principle of the ideal prescription is new and has only been in full operation for a very few years—since the motor-car and the motor-lorry replaced horse transport and reduced the quantity of farm-yard manure. The feeding of the soil population is a very ancient practice and has been employed for many centuries.

The ideal method of dealing with soil fertility appears to lie between these two extremes: in a combination of the advantages of both. One of the objects of this lecture is to suggest that the next generation of Western experiment station workers should adopt all that is best in Chinese agriculture and pay the greatest attention to the humus content of the soil and to the needs of the soil organisms. This should be the foundation-stone of the manurial policy of the future. But in order to avoid misconception it may be as well to state here that the full possibilities of humus are only likely to appear when the dressings of fermented organic matter are supplemented by the addition of suitable artificials. The combination of the two, applied at the right moment and in proper proportions, will open the door to a real era of intensive crop production. Humus and artificials will supplement each other.

[1] King, F. H., *Farmers of Forty Centuries, or Permanent Agriculture in China, Korea and Japan.* London, 1926.

Further, the artificials must not be confined to those which merely supply nitrogen, phosphates and potash. Substances like lime and sulphur, which flocculate the soil colloids and so improve the tilth, must be included. In other words, manuring will have to be both direct and indirect: the soil population and the plant must be fed, the pore-space must be maintained.[1]

II. *THE RÔLE OF HUMUS IN SOIL FERTILITY*

What is the nature and origin of humus and what part does it play in soil fertility?

The various steps in the formation of humus are somewhat as follows: when fresh vegetable and animal residues are added to the soil, the more readily decomposable constituents (sugars, starches, pectins, celluloses, proteins, amino-acids) are attacked by a large number of the micro-organisms present. Decomposition takes place in proportion to the available combined nitrogen present. This is because the active agents in the fermentation are fungi and bacteria, both of which require combined nitrogen. The ratio between the amount of carbohydrate decomposed and the nitrogen required is about 30 : 1, so that for every 30 parts of carbohydrate decomposed by the fungi and bacteria, one part of inorganic nitrogen (ammonium salt or nitrate) will be built up into microbial protoplasm. In the presence of sufficient combined nitrogen and under aerobic conditions the decomposition is very rapid and large quantities of carbon dioxide are evolved. As soon as the readily decomposable constituents of the waste products have disappeared, the speed of decomposition diminishes and a condition of equilibrium tends to become established. Only those portions of the original vegetable and animal wastes like lignified cellulose, which are more resistant to decomposition, now remain.

These and the substances synthesised by the micro-organisms are the main constituents of the soil humus which possesses a carbon : nitrogen ratio in the neighbourhood of 10 : 1.

The soil humus then undergoes a slow decomposition during which its nitrogen is converted into ammonia, which, under favourable conditions, is then transformed into nitrate. This nitrate in dilute solution in water is then taken up by the roots of the crop.[2]

[1] Hall, A. D., "Some Secondary Actions of Manures upon the Soil," *J. R. Agric. Soc.*, 1909, **70**, 12.
[2] S. A. Waksman, "The Origin and Nature of the Soil Organic Matter or Soil 'Humus,'" *Soil Science*, 1926, **22**, 123.

I hope that I have made it clear that the utilisation of vegetable and animal wastes in crop-production involves two definite steps : (1) the formation of humus and its incorporation into the soil mass, and (2) the slow oxidation of this complex product accompanied by the production of available nitrogen. Both of these stages are brought about by micro-organisms for which suitable environmental conditions are essential.

The requirements of the first phase—the preparation of humus and its incorporation into the soil mass—are so intense that if the process takes place in the soil itself it is certain to interfere with the development of the crop. This is because the fungi and bacteria engaged in breaking down the vegetable and animal residues require exactly the same food materials which are essential for the crop—dissolved minerals, including nitrates, and large quantities of oxygen. These facts explain the injurious effects on crop growth which follow the addition of straw and green-manure to the soil.

The decomposition of these materials removes large quantities of combined nitrogen from the soil solution. This nitrogen is then temporarily stored in the form of microbial protoplasm, when, for a time, it is placed beyond the reach of the growing crop.

The needs of the second phase—the utilisation of humus—are much less intense and can proceed in the soil without harm to the growing plant.

From the point of view of crop-production it will be a distinct advantage to separate these two stages and to prepare the humus outside the field rather than in the soil itself. In this matter the Chinese have anticipated the results obtained by Western science. The farmers of forty centuries were the first to grasp and to act upon the master idea that the growth of a crop involves two separate processes ; the preparation of humus from vegetable, animal and human wastes, which must be done outside the field, and the growing of the crop. Only in this way can the soil be protected from overwork.

Besides furnishing the crop with a supply of combined nitrogen, humus influences soil fertility in other ways :

1. The biological properties of humus offer not only a habitat but also a source of energy, nitrogen and minerals for various micro-organisms.
2. The physical properties of humus exert a favourable influence on the tilth, moisture-retaining capacity, and temperature of the soil.
3. The chemical properties of humus enable it to combine with the soil bases and to interact with various salts. It thereby influences the general soil reaction, either acting directly as a weak organic acid or by combining with bases liberating the more highly dissociating organic acids.

These properties—biological, physical and chemical—confer upon humus a place apart in the general work of the soil, including crop-production. It is obvious that this material provides the real basis of successful soil management and of agricultural practice.

III. *THE MANUFACTURE OF HUMUS FROM WASTE PRODUCTS*

The investigation of the humus problem took more than twenty years to complete. The preliminary work was carried out at Pusa and at Quetta. The final process, in which humus was manufactured throughout the year from all kinds of vegetable and animal wastes, was perfected at the Institute of Plant Industry, Indore, between 1924 and 1931.

The Indore method has been taken up at a large number of centres all over the world, including practically all the coffee estates in Kenya and Tanganyika and on a rapidly growing number of the tea estates in India and Ceylon. A brief account of the procedure, as carried out at the moment on the tea estates in India, will make the Indore method clear.

The Humus Factory

A suitable area, conveniently situated for supervision, must first be selected for making humus. The humus factory itself is a very simple affair. At Indore it consists of thirty-three pits, each 30 ft. by 14 ft. and 2 ft. deep, with sloping sides, arranged in three rows with sufficient space between the lines of pits for the easy passage of loaded carts. The pits themselves are in pairs, with a space 12 ft. wide between each pair. This arrangement enables carts to be brought up to any particular pit.

It is often a great advantage to have water laid on, so that the periodical moistening of the compost can be done by means of a hose-pipe. At Indore, water is pumped through a 3-in. pipe into a pressed-steel tank, 8 ft. by 8 ft. by 8 ft. holding 3,200 gallons, which is carried on walls 4 ft. above the ground, to provide the necessary head. This supply lasts about a week. Water is led by 1·5-in. pipes from the tank to eight taps, to which the armoured hose (fitted with a suitable nozzle) can be screwed. Each tap serves about six pits.

The Collection and Storage of Waste Products

The materials needed for the manufacture of humus are the following :

1. *Mixed Plant Residues.* All available vegetable matter of every description from the tea estates—such as weeds, green-manure, fallen leaves, the light prunings of tea bushes and shade trees, trimmings from the road sides and hedges, paddy and other straw and chaff, damaged tea-leaves, tea-waste, wood shavings,

sawdust, waste paper, old gunny bags, and so forth—must be carefully collected and stacked. All hard woody materials—such as the lighter tea and shade-tree prunings and pigeon-pea stalks—are first crushed (by placing on the estate roads) and reduced by the traffic to a condition resembling broken-up paddy straw. *All fresh green materials—such as weeds and green-manure—must be withered before stacking.* To ensure proper mixing, all these dried plant residues must be stacked alongside the humus factory as received, layer by layer—under cover during the rains—so that these materials may be thoroughly mixed. To ensure even mixture, the stacked material is removed to the pits from one end of the stack. The mixing and withering of these plant residues is important for two reasons: to ensure a suitable chemical composition and to prevent undue packing (which cuts off the air supply) in the pits.

2. *Cattle, Buffalo and Horse Dung* (including all soiled bedding from under the animals). This material as well as the droppings of poultry should be collected every morning and broken up into small pieces as it is added to the compost pits.

3. *Urine Earth.* The earth under the cattle, buffaloes and horses should be dug out and renewed to a depth of 6 in. every three or four months. This urine earth should then be powdered in a mortar mill and stored under cover alongside the humus factory.

4. *Ashes.* All wood ashes from the tea factory, bungalows, and coolie lines should be carefully collected and stored under cover alongside the powdered urine earth.

5. *Water and Air.* Water and air are essential for the making of humus and for the fixation of atmospheric nitrogen which takes place during the latter part of the process. Water is most easily applied by an armoured hosepipe with a nozzle which breaks up the stream. An ample supply of air is ensured by the proper mixing of the plant residues and by the use of shallow pits, 2 ft. deep.

Charging and Watering the Compost Pits

Charging. The pits are charged as follows: A layer, about 3 in. deep, of mixed plant residues, is spread lightly and evenly by means of a rake over the floor of the pit. This is then well sprinkled with the dry powdered urine earth to which a few handfuls of ashes have been added. This is followed by a layer, about 2 in. deep, of broken-up dung and soiled bedding. The contents of the pit are well moistened with the hose, care being taken not to flood the pit or to use too much water. The charging process is then continued until the pit is filled to a depth of 30 in. in all, each layer of dung being watered with the hose as before. Care must be taken to finish off each pit with a layer of dung and soiled bedding followed by a good sprinkling of urine earth, ashes and water. The charge must be again watered in the evening and the watering must be repeated the following morning. By applying the first watering in three stages time is given to the mixture to absorb sufficient moisture to start the intense fermentation which rapidly establishes itself. In the charging process it is important to arrange the materials lightly and to avoid consolidation by excessive trampling which is certain to cut off the air supply. This is facilitated by the use of a plank placed across the pits. The level of the contents of the pit, when first charged, is higher than ground level, but rapid shrinkage sets in during the composting process.

Watering. The subsequent waterings are most important. The heaps should be watered once a week and at the time of the first, second and third turn. The aim should be to maintain the heaps moist and mellow (rather than wet) and the temperature high.

Turning the Compost

To ensure uniform mixture and decay and to provide the necessary amount of water and air it is necessary to turn the material three times.

First Turn. When the pit is from ten to fourteen days old it should be turned. Half the pit is dug out with a fork, the contents are moistened and doubled lengthwise over the undisturbed half. The half-turned heap is then watered, care being taken to apply sufficient water and to arrange the materials on the windward side of the pit to prevent cooling and excessive drying.

Second Turn. Fourteen days after the first turn, *i.e.* one month after charging, the material is again turned, watered and piled up loosely along the empty half of the pit.

Third Turn. When the pits are two months old, the dark crumbling material is removed from the pits, moistened and stacked in rectangular heaps—10 ft. broad at the base, 9 ft. wide at the top and 3·5 ft. high—to ripen for a month, when it is ready for the fields.

Humus Manufacture during the Rains

As the pits are full of water during the greater part of the rains, the humus must be made in heaps on the surface between the pits during the heavy monsoon period. During the early rains, all material in the pits must be transferred to heaps on the surface. This is most conveniently done at the time of the first, second or third turn.

Some Simple Means of Testing the Efficiency of Working

The efficiency of the process can be tested by observation and without recourse to chemical or biological analysis.

During the first month, fungi are engaged in breaking down the organic matter. The heaps should then be a mass of white fungoid growth and the temperature should be high. A simple method of testing the temperature is to insert a metal rod which should be hot to the touch when withdrawn.

After the third week the mass darkens rapidly and becomes crumbly, while there is a slight fall in temperature. Bacteria from now onwards take an increasing share in humus manufacture.

If at any time the fermentation stops and the pits cool, want of moisture is the most likely cause.

Should the heaps begin to smell, flies will at once be attracted and will proceed to lay eggs followed by the development of maggots in large numbers. This only happens when there is some interference with the air supply. The remedy is to turn the heap at once and to add dung and ashes. The chief causes of insufficient aeration are excessive trampling, the addition of too much urine earth and ashes, over-watering, or failure to turn the mass at the proper times.

IV. *PRACTICAL APPLICATIONS*

One difficulty, which is not without interest, was encountered in getting the Indore process adopted. Several enthusiastic supporters of the Indore Institute, who were shown the process in an embryonic condition, were so impressed by its possibilities that they insisted on taking it up at once and flatly refused to wait for the final results. The consequence was that their processes had to be perfected as well as my own. In one Indian province a vigorous composting campaign was launched in which one item called for immediate revision. Some difficulty was experienced in getting the necessary amendment made.

I mention this incident, which was constantly happening in India, because there is a general impression in this country that a well-marked time-lag must always occur between the results obtained at an experiment station and their adoption in practice. The conventional view is that after a result is obtained it must be repeated on a large number of replicated and randomised plots and the figures must then be subjected to a rigid statistical examination. The idea seems to be to protect the farmer from false prophets, forgetting that he is perfectly capable of looking after himself. My experience contradicts this conventional view of the time lag. When results of real practical value have been obtained in India I never observed any delay in their adoption. The response on the part of the cultivators was immediate. There was therefore no opportunity for spending time on the replication and randomisation processes. The only difficulty met with was illiteracy. Propaganda was impossible by means of print, a circumstance which greatly reduced the rate at which improvements could be taken up over large areas.

An account of the Indore process was published in book form at the end of 1931.[1]

During 1932 and 1933 the process was taken up successfully at a number of centres both in India and in other countries. At the same time it was applied to the conversion of municipal wastes—night soil and bazaar refuse—at Indore.[2]

An account of the progress made up to the end of 1933 is to be found in the *Journal of the Royal Society of Arts* of December 8th, 1933. The results described in this paper brought out very clearly the great elasticity of the process and the ease with which it could be incorporated into many different types of agriculture conducted under a wide range of climatic and labour conditions. One outstanding advantage has proved to be its cheapness. On one tea estate in South India, for example, it has been possible to keep down the cost of manufacturing humus to a shilling a ton.

During 1934 and 1935 progress has been rapid and many new and interesting developments have taken place. These will be dealt with in a lecture to the Royal Society of Arts in November next. Copies of this lecture will be made available for the use of the members of this Society who are interested in the work. I need therefore spend no time in dealing with practical applications.

V. *HUMUS AND DISEASE-RESISTANCE IN PLANTS AND ANIMALS*

The conversion of waste products into humus and its application to the land does not end with a more fertile soil and an increase in yield. This is only the first result. Humus influences the natural resistance of plants to the inroads of insects and fungi. Moreover, such disease-resistant plants when used as fodder appear in turn to confer on animals a high degree of immunity to infectious animal diseases. These matters will now be considered in detail.

Disease Resistance in Plants. It is commonly supposed that insects and fungi are the cause of most of the diseases in plants. I once held this view myself and spent three years on mycological work during which I wrote a number of papers on the diseases of such crops as sugar-cane and cacao. After a long experience in plant breeding during which many thousands of unit species were raised, many of which were often repeated on different types of soil for a number of years, I began to realise that the conventional views on the cause of plant diseases would have to be abandoned.

[1] Howard, A., and Wad, Y. D., *The Waste Products of Agriculture: their Utilization as Humus.* Oxford University Press, 1931.

[2] Jackson, F. K., and Wad, Y. D., "The Sanitary Disposal and Agricultural Utilization of Habitation Wastes by the Indore Process," *The Indian Medical Gazette*, LXIX, No. 2, Feb., 1934.

Both fungi and insects were observed to have an extraordinary distaste for certain unit species and to leave them severely alone. Such cultures were not even attacked when abundant infection was provided for weeks at a time. The immunity persisted year after year. At Pusa where some attention was paid to the factors underlying this immunity it was found that there was a definite connection between the degree of infection and the type of root-system. On this alluvial soil unit species with a high degree of immunity were always surface rooted. A deep rooting habit on the other hand always meant extreme susceptibility. Unit species with an intermediate type of root system were moderately susceptible. In the case of *Lathyrus sativus* L. the degree of correspondence between the type of root system and green-fly infection was perfect and repeated itself year after year. But another factor which was found to operate was the humus content of the soil. Given a variety with a type of root system suitable for the locality it was frequently observed that crops grown on land manured with humus were always remarkably free, both from insects and fungoid diseases. The presence of abundant infection in the immediate neighbourhood made no difference. Such well-grown crops offered no attractions to the pests. This suggests that immunity depends on a combination of at least two factors of which the humus content and the soil is certainly one.

This experience closely corresponds with that of the sugar industry in Java. The Indian Sugar Committee, in dealing with the methods in use in Java for combating the diseases of the sugar-cane, stated in their report: "It is held that proper methods of cultivation and the introduction of good varieties are the most important factors in the control and elimination of diseases." In the early days of the Java sugar industry considerable attention was paid to the investigation of insect and fungoid diseases, the cost of which was borne by the planters themselves. It is most significant that for some years past direct methods have been given up and that attention is now concentrated solely on the variety and on its proper cultivation. A visitor to Java, on his return to India some years ago, stated that an outbreak of the red-rot fungus on a sugar estate in that Colony would involve the dismissal of the manager, because experience has shown that this disease only occurs as a result either of improper methods of agriculture or of the cultivation of unsuitable varieties.

These observations on immunity suggest a new line of thought. What use should experiment station workers make of the insects and fungi associated with plant diseases? What are insects and fungi for? My own view is that these organisms are invaluable censors, provided by Nature for checking our proceedings as agriculturists and for keeping things up to the mark. They should therefore be carefully preserved and their activities closely

observed and pondered over. The present policy of destruction by means of sprays and powders is, in my opinion, throughly unscientific and unsound. When a disease appears on an experiment station things should be allowed to take their course. Our varieties and our practice should then be subjected to a severe and searching examination and every endeavour should be made to find out what is wrong. If this examination is to produce results it may have to be carried backwards for some months and also forwards after the trouble has died down. I should like to quote two examples out of many which illustrate the need for a complete study not only of the disease but also of the predisposing factors.

In June, 1910, during my first leave from India, I was asked to investigate an obscure disease of cherries near Faversham and was shown a number of learned reports on the insects which appeared to be concerned. The appearance of the trees, however, suggested root trouble. Investigation showed that the smaller roots had been killed, apparently by fungi, and that active sheets of mycelia were destroying the cambium of the larger roots and making their way towards the trunk. The condition of the subsoil pointed unmistakably to long-continued water-logging. It then transpired that the preceding autumn and winter had been the wettest on record. I was able to comfort the grower that time, rather than an entomologist, was required to put things right.

The second example concerns an insect attack at Indore in Central India in 1928. In July of that year one of the monsoon fallow plots was partly inundated for some days by the temporary stoppage of one of the drainage canals. The water-logged area was duly recorded on the plan of the plot in the ordinary routine. Early in the following October the plot was sown with gram (*Cicerarietinum* L). In November the gram caterpillar appeared on this particular plot and made very rapid headway. Some of the members of the Indian staff became alarmed as it was thought the pest would spread to the other 50 acres under this crop. I decided to do nothing and to wait and see what happened. It soon became evident that the attack was dying down and was not going to spread. The crop on a portion of the plot only was destroyed. When the infection plan was compared with the inundation plan of the previous July the two were found to fit exactly. Clearly the cause of the trouble was some interference in metabolism resulting from changes in the soil following the inundation.

I mention these examples among many in the hope that something will soon be done (1) to place mycological and entomological research on a much more scientific basis than is now the case and (2) to provide our future mycologists and entomologists with an area of land on which they can learn how to grow crops so that these studies can be used to lead practice to higher levels and will not be content with burdening the literature with learned accounts of still more diseases.

Disease-Resistance in Animals. I should like to take this opportunity of drawing the attention of workers on the diseases of animals in this country to the results of more than twenty years' experience in India on the effect of fodder crops grown on land rich in humus on the incidence of epidemic disease. At three centres—Pusa in the Indo-Gangetic plain, Quetta on the North-West Frontier, and Indore on the black cotton soils of Central India—I was compelled by circumstances to raise the food of the work cattle in my charge by intensive methods from a small area. During this period I worked with four breeds of oxen—Kheri, Gujerati, Sibi, and Malvi—and utilised at all three centres thirty pairs of animals in all. The most careful attention was paid to the food and to the general hygiene, but in no case were any of the animals ever inoculated against the various diseases. On the contrary, they were allowed to mix freely with and to share the pastures of all kinds of infected stock. Nevertheless, not a single case of disease occurred notwithstanding the many epidemics of foot-and-mouth disease, rinderpest, septicæmia, and so forth, which frequently swept over the locality. Here we have immunity in cattle resulting from perfect gear between three factors: the root-system of the fodder crop; a soil rich in humus; a breed suited to the locality. I should not be surprised to find that similar results can be obtained in this country. We appear to be tackling such things as foot-and-mouth disease and bovine tuberculosis at the wrong end. Something is almost certain to be wrong with the food of our stock and possibly with the breed and the general hygiene as well. I suggest that some research centre should take up this matter and work out the chain—(*a*) drainage, lime and humus, (*b*) quality of plant products, and (*c*) disease resistance of stock—in detail. The results would be of the greatest value to our stockmen and would even pave the way to the study of the relation which almost certainly exists between the quality and freshness of food and the health of the human population.

One of the pioneers of intensive vegetable growing in this country is convinced that really high quality vegetables can only be produced when humus of animal origin is applied to the land. I believe these views are well founded and will in due course be accepted. They open out a wide field of fruitful research.

Everything seems to be pointing to the supreme importance of properly grown food both for man and beast. One of the great problems of the future is to discover how to make the very fullest use of the energy of sunlight by means of the green plant so that immunity to disease both of plants, of animals and also of mankind, is the natural result. Economic Botany will then become a branch of preventive medicine and in this way the

foundations of a scientific system of public health will be laid. At the same time a vast field for research will be provided which will occupy the energies of biological investigators for at least a generation. But such investigators must be more than specialists. They must be properly and adequately trained, capable of taking wide views and able to bring knowledge simultaneously to bear on the problem in hand from any direction.

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