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SIR ALBERT HOWARD, C.I.E., M.A.

Formerly Director of the Institute of Plant Industry Indore, and

Agricultural Adviser to States in Central India and Rajputana

TO

GABRIELLE

WHO IS NO MORE

The Earth, that's Nature's Mother, is her tomb;

What is her burying grave, that is her womb.

Romeo and Juliet.

And Nature, the old nurse, took

The child upon her knee,

Saying: 'Here is a story-book

Thy Father has written for thee.'
'Come, wander with me,' she said,

'Into regions yet untrod;

And read what is still unread

In the manuscripts of God.'

LONGFELLOW

The Fiftieth Birthday of Agassiz.

PREFACE

Since the Industrial Revolution the processes of growth have been speeded up to produce the food and raw materials needed by the population and the factory. Nothing effective has been done to replace the loss of fertility involved in this vast increase in crop and animal production. The consequences have been disastrous. Agriculture has become unbalanced: the land is in revolt: diseases of all kinds are on the increase: in many parts of the world Nature is removing the worn-out soil by means of erosion.

The purpose of this book is to draw attention to the destruction of the earth's capital--the soil; to indicate some of the consequences of this; and to suggest methods by which the lost fertility can be restored and

maintained. This ambitious project is founded on the work and experience
of forty years, mainly devoted to agricultural research in the West Indies, India, and Great Britain. It is the continuation of an earlier book--The Waste Products of Agriculture, published in 1931--in which the Indore method for maintaining soil fertility by the manufacture of humus from vegetable and animal wastes was described.

During the last nine years the Indore Process has been taken up at many centres all over the world. Much additional information on the role of humus in agriculture has been obtained. I have also had the leisure to bring under review the existing systems of farming as well as the organization and purpose of agricultural research. Some attention has also been paid to the bio-dynamic methods of agriculture in Holland and in Great Britain, but I remain unconvinced that the disciples of Rudolph Steiner can offer any real explanation of natural laws or have yet provided any practical examples which demonstrate the value of their theories.

The general results of all this are set out in this my Agricultural Testament. No attempt has been made to disguise the conclusions reached or to express them in the language of diplomacy. On the contrary, they have been stated with the utmost frankness. It is hoped that they will be discussed with the same freedom and that they will open up new lines of thought and eventually lead to effective action.

It would not have been possible to have written this book without the help and encouragement of a former colleague in India, Mr. George Clarke, C.I.E., who held the post of Director of Agriculture in the United Provinces for ten years (1921-31). He very generously placed at my disposal his private notes on the agriculture of the Provinces covering a period of over twenty years, and has discussed with me during the last three years practically everything in this book. He read many of the Chapters when they were first drafted, and made a number of suggestions which have been incorporated in the text.

Many who are engaged in practical agriculture all over the world and who have adopted the Indore Process have contributed to this book. In a few cases mention of this assistance has been made in the text. It is impossible to refer to all the correspondents who have furnished progress reports and have so freely reported their results. These provided an invaluable collection of facts and observations which has amply confirmed my own experience.

Great stress has been laid on a hitherto undiscovered factor in nutrition--the mycorrhizal association--the living fungous bridge between humus in the soil and the sap of plants. The existence of such a symbiosis was first suggested to me on reading an account of the remarkable results with conifers, obtained by Dr. M. C. Rayner at Wareham in Dorset in connexion with the operations of the Forestry Commission. If mycorrhiza occurs generally in the plantation industries and also in our crops, an explanation of such things as the development of quality, disease resistance, and the running out of the variety, as well as the slow deterioration of the soil which follows the use of artificial manures, would be provided. I accordingly took steps to collect a wide range of specimens likely to contain mycorrhiza, extending over the whole of tropical and temperate agriculture. I am indebted to Dr. Rayner and to Dr. Ida Levisohn for the detailed examination of this material. They have furnished me with many valuable and suggestive technical reports. For the interpretation of these laboratory results, as set out in the following pages, I am myself solely responsible.

I am indebted to a number of Societies for permission to reproduce information and illustrations which have already been published. Two other organizations have allowed me to incorporate results which might well have been regarded as confidential. The Royal Society of London has permitted me to reprint, in the Chapter on Soil Aeration, a precis of an illustrated paper which appeared in their Proceedings. The Royal Society of Arts has provided the blocks for the section on sisal waste. The Royal Sanitary Institute has agreed to the reproduction in full of a paper read at the Health Congress, held at Portsmouth in July 1938. The British Medical Journal has placed at my disposal the information contained in an article by Dr. Lionel J. Picton, O.B.E. The publishers of Dr. Waksman's monograph on Humus have allowed me to reprint two long extracts relating to the properties of humus. Messrs. Arthur Guinness, Sons & Co., Limited, have agreed to the publication of the details of the composting of town wastes in their hop garden at Bodiam. Messrs. Walter Duncan & Co. have allowed the Manager of the Gandrapara Tea Garden to contribute an illustrated article on the composting of wastes on this fine estate. Captain J. M. Moubray has sent me a very interesting summary of the work he is doing at Chipoli in Southern Rhodesia, which is given in Appendix B.

In making the Indore Process widely known, a number of journals have rendered yeoman service. In Great Britain The Times and the Journal of the Royal Society of Arts have published a regular series of letters and articles. In South Africa the Farmer's Weekly has from the beginning urged the agricultural community to increase the humus content of the soil. In Latin America the planters owe much to the Revista del Instituto de Defensa del Cafe de Costa Rica.

Certain of the largest tea companies in London, Messrs. James Finlay & Co., Walter Duncan & Co., the Ceylon Tea Plantations Company, Messrs. Octavius Steel & Co., and others, most generously made themselves responsible over a period of two years for a large part of the office expenses connected with the working out and application to the plantation industries of the Indore Process. They also defrayed the expenses of a tour to the tea estates of India and Ceylon in 1937. These arrangements were very kindly made on my behalf by Mr. G. H. Masefield, Chairman of the Ceylon Tea Plantations Company.

In the work of reducing to order the vast mass of correspondence and notes on soil fertility' which have accumulated, and in getting the book into its final shape, I owe much to the ability and devotion of my private secretary, Mrs. V. M. Hamilton.

A. H. BLACKHEATH,

1 January 1940

In deciding to issue a fifth reprint of my late husband's book, An Agricultural Testament, I have abstained from introducing any additions or corrections. To do so would necessitate an almost complete rewriting of this, the first and perhaps the most trenchant, statement of his views. Nevertheless, it would be incorrect to deny that the subject matters treated progressed rapidly even in the course of his own life time; he himself added to what he said here, and many gallant writers have followed his lead. A survey of literature presents difficulties, partly owing to Sir Albert Howard's practice of scattering articles in journals all over the world. Following on the creation of an Albert Howard Foundation of Organic Husbandry, the declared aim of which is to continue and make known the Albert Howard principles, inquiries may be addressed to the Headquarters of the Foundation at Sharnden Manor, Mayfield, Sussex, England.

LOUISE E. HOWARD

1949

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CHAPTER I

INTRODUCTION

The maintenance of the fertility of the soil is the first condition of any permanent system of agriculture. In the ordinary processes of crop production fertility is steadily lost: its continuous restoration by means of manuring and soil management is therefore imperative.

In the study of soil fertility the first step is to bring under review the various systems of agriculture which so far have been evolved. These fall into four main groups: (1) the methods of Nature--the supreme farmer--as seen in the primeval forest, in the prairie, and in the ocean; (2) the agriculture of the nations which have passed away; (3) the practices of the Orient, which have been almost unaffected by Western science; and (4) the methods in vogue in regions like Europe and North America to which a large amount of scientific attention has been paid during the last hundred years.

NATURE'S METHODS OF SOIL MANAGEMENT

Little or no consideration is paid in the literature of agriculture to the means by which Nature manages land and conducts her water culture. Nevertheless, these natural methods of soil management must form the basis of all our studies of soil fertility.

What are the main principles underlying Nature's agriculture? These can most easily be seen in operation in our woods and forests.

Mixed farming is the rule: plants are always found with animals: many species of plants and of animals all live together. In the forest every form of animal life, from mammals to the simplest invertebrates, occurs. The vegetable kingdom exhibits a similar range: there is never any attempt at monoculture: mixed crops and mixed farming are the rule.

The soil is always protected from the direct action of sun, rain, and wind. In this care of the soil strict economy is the watchword: nothing is lost. The whole of the energy of sunlight is made use of by the foliage of the forest canopy and of the undergrowth. The leaves also break up the rainfall into fine spray so that it can the more easily be dealt with by the litter of plant and animal remains which provide the last line of defence of the precious soil. These methods of protection, so effective in dealing with sun and rain, also reduce the power of the strongest winds to a gentle air current.

The rainfall in particular is carefully conserved. A large portion is retained in the surface soil: the excess is gently transferred to the subsoil and in due course to the streams and rivers. The fine spray created by the foliage is transformed by the protective ground litter into thin films of water which move slowly downwards, first into the humus layer and then into the soil and subsoil. These latter have been made porous in two ways: by the creation of a well-marked crumb structure and by a network of drainage and aeration channels made by earthworms and other burrowing animals. The pore space of the forest soil is at its maximum so that there is a large internal soil surface over which the thin films of water can creep. There is also ample humus for the direct absorption of moisture. The excess drains away slowly by way of the subsoil. There is remarkably little run-off, even from the primeval rain forest. When this occurs it is practically clear water. Hardly any soil is removed. Nothing in the nature of soil erosion occurs. The streams and rivers in forest areas are always perennial because of the vast quantity of water in slow transit between the rainstorms and the sea. There is therefore little or no drought in forest areas because so much of the rainfall is retained exactly where it is needed. There is no waste anywhere.

The forest manures itself. It makes its own humus and supplies itself with minerals. If we watch a piece of woodland we find that a gentle accumulation of mixed vegetable and animal residues is constantly taking place on the ground and that these wastes are being converted by fungi and bacteria into humus. The processes involved in the early stages of this transformation depend throughout on oxidation: afterwards they take place in the absence of air. They are sanitary. There is no nuisance of any kind--no smell, no flies, no dustbins, no incinerators, no artificial sewage system, no water-borne diseases, no town councils, and no rates. On the contrary, the forest affords a place for the ideal summer holiday: sufficient shade and an abundance of pure fresh air. Nevertheless, all over the surface of the woods the conversion of vegetable and animal wastes into humus is never so rapid and so intense as during the holiday months--July to September.

The mineral matter needed by the trees and the undergrowth is obtained from the subsoil. This is collected in dilute solution in water by the deeper roots, which also help in anchoring the trees. The details of root distribution and the manner in which the subsoil is thoroughly combed for minerals are referred to in a future chapter. Even in soils markedly deficient in phosphorus trees have no difficulty in obtaining ample supplies of this element. Potash, phosphate, and other minerals are always collected in situ and carried by the transpiration current for use in the green leaves. Afterwards they are either used in growth or deposited on the floor of the forest in the form of vegetable waste--one of the constituents needed in the synthesis of humus. This humus is again utilized by the roots of the trees. Nature's farming, as seen in the forest, is characterized by two things: (1) a constant circulation of the mineral matter absorbed by the trees; (2) a constant addition of new mineral matter from the vast reserves held in the subsoil. There is therefore no need to add phosphates: there is no necessity for more potash salts. No mineral deficiencies of any kind occur. The supply of all the manure needed is automatic and is provided either by humus or by the soil. There is a natural division of the subject into organic and inorganic. Humus provides the organic manure: the soil the mineral matter.

The soil always carries a large fertility reserve. There is no hand to mouth existence about Nature's farming. The reserves are carried in the upper layers of the soil in the form of humus. Yet any useless accumulation of humus is avoided because it is automatically mingled with the upper soil by the activities of burrowing animals such as earthworms and insects. The extent of this enormous reserve is only realized when the trees are cut down and the virgin land is used for agriculture. When plants like tea, coffee, rubber, and bananas are grown on recently cleared land, good crops can be raised without manure for ten years or more. Like all good administrators, therefore, Nature carries strong liquid reserves effectively invested. There is no squandering of these reserves to be seen anywhere.

The crops and live stock look after themselves. Nature has never found it necessary to design the equivalent of the spraying machine and the poison spray for the control of insect and fungous pests. There is nothing in the nature of vaccines and serums for the protection of the live stock. It is true that all kinds of diseases are to be found here and there among the plants and animals of the forest, but these never assume large proportions. The principle followed is that the plants and animals can very well protect themselves even when such things as parasites are to be found in their midst. Nature's rule in these matters is to live and let live.

If we study the prairie and the ocean we find that similar principles are followed. The grass carpet deals with the rainfall very much as the forest does. There is little or no soil erosion: the run-off is practically clear water. Humus is again stored in the upper soil. The best of the grassland areas of North America carried a mixed herbage which maintained vast herds of bison. No veterinary service was in existence for keeping these animals alive. When brought into cultivation by the early settlers, so great was the store of fertility that these prairie soils yielded heavy crops of wheat for many years without live stock and without manure.

In lakes, rivers, and the sea mixed farming is again the rule: a great variety of plants and animals are found living together: nowhere does one find monoculture. The vegetable and animal wastes are again dealt with by effective methods. Nothing is wasted. Humus again plays an important part and is found everywhere in solution, in suspension, and in the deposits of mud. The sea, like the forest and the prairie, manures itself.

The main characteristic of Nature's farming can therefore be summed up in a few words. Mother earth never attempts to farm without live stock; she always raises mixed crops; great pains are taken to preserve the soil and to prevent erosion; the mixed vegetable and animal wastes are converted into humus; there is no waste; the processes of growth and the processes of decay balance one another; ample provision is made to maintain large reserves of fertility; the greatest care is taken to store the rainfall; both plants and animals are left to protect themselves against disease

In considering the various man-made systems of agriculture, which so far have been devised, it will be interesting to see how far Nature's principles have been adopted, whether they have ever been improved upon, and what happens when they are disregarded.

THE AGRICULTURE OF THE NATIONS WHICH HAVE PASSED AWAY

The difficulties inherent in the study of the agriculture of the nations which are no more are obvious. Unlike their buildings, where it is possible from a critical study of the buried remains of cities to reproduce a picture of bygone civilizations, the fields of the ancients have seldom been maintained. The land has either gone back to forest or has been used for one system of farming after another.

In one case, however, the actual fields of a bygone people have been preserved together with the irrigation methods by which these lands were made productive. No written records, alas, have come down to us of the staircase cultivation of the ancient Peruvians, perhaps one of the oldest forms of Stone Age agriculture. This arose either in mountains or in the upland areas under grass because of the difficulty, before the discovery of iron, of removing the dense forest growth. In Peru irrigated staircase farming seems to have reached its highest known development. More than twenty years ago the National Geographical Society of the United States sent an expedition to study the relics of this ancient method of agriculture, an account of which was published by O. F. Cook in the Society's Magazine of May 1916, under the title: 'Staircase Farms of the Ancients.' The system of the megalithic people of old Peru was to construct a stairway of terraced fields up the slopes of the mountains, tier upon tier, sometimes as many as fifty in number. The outer retaining walls of these terraces were made of large stones which fit into one another with such accuracy that even at the present day, like those of the Egyptian pyramids, a knife blade cannot be inserted between them. After the retaining wall was built, the foundation of the future field was prepared by means of coarse stones covered with clay. On this basis layers of soil, several feet thick, originally imported from beyond the great mountains, were super-imposed and then levelled for irrigation. The final result was a small flat field with only just sufficient slope for artificial watering. In other words, a series of huge flower pots, each provided with ample drainage below, was prepared with incredible labour by this ancient people for their crops. Such were the megalithic achievements in agriculture, beside which 'our undertakings sink into insignificance in face of what this vanished race accomplished. The narrow floors and steep walls of rocky valleys that would appear utterly worthless and hopeless to our engineers were transformed, literally made over, into fertile lands and were the homes of teeming populations in pre-historic days' (O. F. Cook). The engineers of old Peru did what they did through necessity because iron, steel, reinforced concrete, and the modern power units had not been invented. The plunder of the forest soil was beyond their reach.

These terraced fields had to be irrigated. Water had to be led to them over immense distances by means of aqueducts. Prescott states that one which traversed the district of Condesuyu measured between four and five hundred miles. Cook gives a photograph of one of these channels as a thin dark line traversing a steep mountain wall many hundreds of feet above the valley.

These ancient methods of agriculture are represented at the present day by the terraced cultivation of the Himalayas, of the mountainous areas of China and Japan, and of the irrigated rice fields so common in the hills of South India, Ceylon, and the Malayan Archipelago. Conway's description, published in 1894, of the terraces of Hunza on the North-West Frontier of India and of the canal, carried for long distances across the face of precipices to the one available supply of perennial water--the torrent from the Ultor glacier--tallies almost completely with what he found in 1901 in the Bolivian Andes. This distinguished scholar and mountaineer considered that the native population of Hunza of the present day is living in a stage of civilization that must bear no little likeness to that of the Peruvians under Inca government. An example of this ancient method of farming has thus been preserved through the ages. In a future chapter the relation which exists between the nutritional value of the food grown on these irrigated terraces and the health of the people will be discussed. This relic of the past is interesting from the point of view of quality in food as well as from its historical value.

Some other systems of agriculture of the past have come down to us in the form of written records which have furnished ample material for constructive research. In the case of Rome in particular a fairly complete account of the position of agriculture, from the period of the monarchy to the fall of the Roman Empire, is available; the facts can be conveniently followed in the writings of Mommsen, Heitland, and other scholars. In the case of Rome the Servian Reform (Servius Tullius, 578-534 B.C.) shows very clearly not only that the agricultural class originally preponderated in the State but also that an effort was made to maintain the collective body of freeholders as the pith and marrow of the community. The conception that the constitution itself rested on the freehold system permeated the whole policy of Roman war and conquest. The aim of war was to increase the number of its freehold members.

'The vanquished community was either compelled to merge entirely into the yeomanry of Rome, or, if not reduced to this extremity, it was required, not to pay a war contribution or a fixed tribute, but to cede a portion, usually a third part, of its domain, which was thereupon regularly occupied by Roman farms. Many nations have gained victories and made conquests as the Romans did; but none has equalled the Roman in thus making the ground he had won his own by the sweat of his brow, and in securing by the ploughshare what had been gained by the lance. That which is gained by war may be wrested from the grasp by war again, but it is not so with the conquests made by the plough; whilst the Romans lost many battles, they scarcely ever on making peace ceded Roman soil, and for this result they were indebted to the tenacity with which the farmers clung to their fields and homesteads. The strength of man and of the State lies in their dominion over the soil; the strength of Rome was built on the most extensive and immediate mastery of her citizens over the soil, and on the compact unity of the body which thus acquired so firm a hold.' (Mommsen.)

These splendid ideals did not persist. During the period which elapsed between the union of Italy and the subjugation of Carthage, a gradual decay of the farmers set in; the small-holdings ceased to yield any substantial clear return; the cultivators one by one faced ruin; the moral tone and frugal habits of the earlier ages of the Republic were lost; the land of the Italian farmers became merged into the larger estates. The landlord capitalist became the centre of the subject. He not only produced at a cheaper rate than the farmer because he had more land, but he began to use slaves. The same space which in the olden time, when small-holdings prevailed, had supported from a hundred to a hundred and fifty families was now occupied by one family of free persons and about fifty, for the most part unmarried, slaves. 'If this was the remedy by which the decaying national economy was to be restored to vigour, it bore, unhappily, an aspect of extreme resemblance to disease' (Mommsen). The main causes of this decline appear to have been fourfold: the constant drain on the manhood of the country-side by the legions, which culminated in the two long wars with Carthage; the operations of the Roman capitalist landlords which 'contributed quite as much as Hamilcar and Hannibal to the decline in the vigour and the number of the Italian people' (Mommsen); failure to work out a balanced agriculture between crops and live stock and to maintain the fertility of the soil; the employment of slaves instead of free labourers. During this period the wholesale commerce of Latium passed into the hands of the large landed proprietors who at the same time were the speculators and capitalists. The natural consequence was the destruction of the middle classes, particularly of the small-holders, and the development of landed and moneyed lords on the one hand and of an agricultural proletariat on the other. The power of capital was greatly enhanced by the growth of the class of tax-farmers and contractors to whom the State farmed out its indirect revenues for a fixed sum. Subsequent political and social conflicts did not give real relief to the agricultural community. Colonies founded to secure Roman sovereignty over Italy provided farms for

the agricultural proletariat, but the root causes of the decline in agriculture were not removed in spite of the efforts of Cato and other reformers. A capitalist system of which the apparent interests were fundamentally opposed to a sound agriculture remained
supreme. The last half of the second century saw degradation and more and more decadence. Then came Tiberius Gracchus and the Agrarian Law with the appointment of an official commission to counteract the diminution of the farmer class by the comprehensive establishment of new small-holdings from the whole Italian landed property at the disposal of the State: eighty thousand new Italian farmers were provided with land. These efforts to restore agriculture to its rightful place in the State were accompanied by many improvements in Roman agriculture which, unfortunately, were most suitable for large estates. Land no longer able to produce corn became pasture; cattle now roamed over large ranches; the vine and the olive were cultivated with commercial success. These systems of agriculture, however, had to be carried on with slave labour, the supply of which had to be maintained by constant importation. Such extensive methods of farming naturally failed to supply sufficient food for the population of Italy. Other countries were called upon to furnish essential foodstuffs; province after province was conquered to feed the growing proletariat with corn. These areas in turn slowly yielded to the same decline which had taken place in Italy. Finally the wealthy classes abandoned the depopulated remnants of the mother country and built themselves a new capital at Constantinople. The situation had to be saved by a migration to fresh lands. In their new capital the Romans relied on the unexhausted fertility of Egypt as well as on that of Asia Minor and the

Balkan and Danubian provinces.

Judged by the ordinary standards of achievement the agricultural history of the Roman Empire ended in failure due to inability to realize the fundamental principle that the maintenance of soil fertility coupled with the legitimate claims of the agricultural population should never have been allowed to come in conflict with the operations of the capitalist. The most important possession of a country is its population. If this is maintained in health and vigour everything else will follow; if this is allowed to decline nothing, not even great riches, can save the country from eventual ruin. It follows, therefore, that the strongest possible support of capital must always be a prosperous and contented country-side. A working compromise between agriculture and finance should therefore have been evolved. Failure to achieve this naturally ended in the ruin of both.

THE PRACTICES OF THE ORIENT

In the agriculture of Asia we find ourselves confronted with a system of peasant farming which in essentials soon became stabilized. What is happening to-day in the small fields of India and China took place many centuries ago. There is here no need to study historical records or to pay a visit to the remains of the megalithic farming of the Andes. The agricultural practices of the Orient have passed the supreme test--they are almost as permanent as those of the primeval forest, of the prairie or of the ocean. The small-holdings of China, for example, are still maintaining a steady output and there is no loss of fertility after forty centuries of management. What are the chief characteristics of this Eastern farming?

The holdings are minute. Taking India as an example, the relation between man power and cultivated area is referred to in the Census Report of 1931 as follows: 'For every agriculturalist there is 2.9 acres of cropped land of which 0.65 of an acre is irrigated. The corresponding figures of 1921 are 2.7 and 0.61.' These figures illustrate how intense is the struggle for existence in this portion of the tropics. These small-holdings are often cultivated by extensive methods (those suitable for large areas) which utilize neither the full energies of man or beast nor the potential fertility of the soil.

If we turn to the Far East, to China and Japan, a similar system of small-holdings is accompanied by an even more intense pressure of population both human and bovine. In the introduction to FARMERS OF FORTY CENTURIES, King states that the three main islands of Japan had in 1907 a population of 46,977,000, maintained on 20,000 square miles of cultivated fields. This is at the rate of 2,349 to the square mile or more than three people to each acre. In addition, Japan fed on each square mile of cultivation a very large animal population--69 horses and 56 cattle, nearly all employed in labour; 825 poultry; 13 swine, goats, and sheep. Though no accurate statistics are available in China, the examples quoted by King reveal a condition of affairs not unlike that in Japan. In the Shantung Province a farmer with a family of twelve kept one donkey, one cow, and two pigs on 2.5 acres of cultivated land--a density of population at the rate of 3,072 people, 256 donkeys, 256 cattle, and 512 pigs per square mile. The average of seven Chinese holdings visited gave a maintenance capacity of 1,783 people, 212 cattle or donkeys, and 399 pigs--nearly 2,000 consumers and 400 rough food transformers per square mile of farmed land. In comparison with these remarkable figures, the corresponding statistics for 1900 in the case of the United States per square mile were: population 61, horses and mules 30.

Food and forage crops are predominant. The primary function of Eastern agriculture is to supply the cultivators and their cattle with food. This automatically follows because of the pressure of the population on the land: the main hunger the soil has to appease is that of the stomach. A subsidiary hunger is that of the machine which needs raw materials for manufacture. This extra hunger is new but has developed considerably since the opening of the Suez Canal in 1869 (by which the small fields of the cultivator have been brought into effective contact with the markets of the West) and the establishment of local industries like cotton and jute. To both these hungers soil fertility has to respond. We know from long experience that the fields of India can respond to the hunger of the stomach. Whether they can fulfil the added demands of the machine remains to be seen. The Suez Canal has only been in operation for seventy years. The first cotton mill in India was opened in 1818 at Fort Gloster, near Calcutta. The jute industry of Bengal has grown up within a century. Jute was first exported in 1838. The first jute mill on the Hoogly began operations in 1855. These local industries as well as the export trade in raw products for the use of the factories of the West are an extra drain on soil fertility. Their future well-being and indeed their very existence is only possible provided adequate steps are taken to maintain this fertility. There is obviously no point in establishing cotton and jute mills in India, in founding trading agencies like those of Calcutta and in building ships for the conveyance of raw products unless such enterprises are stable and permanent. It would be folly and an obvious waste of capital to pursue such activities if they are founded only on the existing store of soil fertility. All concerned in the hunger of the machine--government, financiers, manufacturers, and distributors--must see to it that the fields of India are equal to the new burden which has been thrust upon her during the last fifty years or so. The demands of commerce and industry on the one hand and the fertility of the soil on the other must be maintained in correct relation the one to the other.

The response of India to the two hungers--the stomach and the machine--will be evident from a study of Table I, in which the area in acres under food and fodder crops is compared with that under money crops.

The chief food crops in order of importance are rice, pulses millets, wheat, and fodder crops. The money crops are more varied; cotton and oil seeds are the most important, followed by jute and other fibres, tobacco, tea, coffee, and opium. It will be seen that food and fodder crops comprise 86 per cent. of the total area under crops and that money crops, as far as extent is concerned, are less important, and constitute only one-seventh of the total cultivated area.

TABLE 1

Agricultural Statistics of British India, 1935-6

Area, in acres, under food and fodder crops
Rice 79,888,000

Millets 38,144,000

Wheat 25,150,000

Gram 14,897,000

Pulses and other food grains 29,792,000

Fodder crops 10,791,000 Condiments, spices,

fruits, vegetables

and miscellaneous food crops 8,308,000

Barley 6,178,000

Maize 6,211,000

Sugar 4,038,000

Total food and fodder crops 223,397,000

Area, in acres, under money crops

Cotton 15,761,000

Oil seeds, chiefly ground-nuts,

sesamum, rape, mustard and linseed 15,662,000

Jute and other fibres 2,706,000 Dyes, tanning

materials, drugs,

narcotics, and miscellaneous 1,458,000

Tobacco 1,230,000

Tea 787,000

Coffee 97,000

Indigo 40,000
Opium 10,000

Total money crops 37,751,000

One interesting change in the production of Indian food crops has taken place during the last twenty-five years. The output of sugar used to be insufficient for the towns, and large quantities were imported from Java, Mauritius, and the continent of Europe. To-day, thanks to the work at Shahjahanpur in the United Provinces, the new varieties of cane bred at Coimbatore and the protection now enjoyed by the sugar industry, India is almost self-supporting as far as sugar is concerned. The pre-war average amount of sugar imported was 634,000 tons; in 1937-8 the total had fallen to 14,000 tons.

Mixed crops are the rule. In this respect the cultivators of the Orient have followed Nature's method as seen in the primeval forest. Mixed cropping is perhaps most universal when the cereal crop is the main constituent.

Crops like millets, wheat, barley, and maize are mixed with an appropriate subsidiary pulse, sometimes a species that ripens much later than the cereal. The pigeon pea (Cajanus indicus Spreng.), perhaps the most important leguminous crop of the Gangetic alluvium, is grown either with millets or with maize. The mixing of cereals and pulses appears to help both crops. When the two grow together the character of the growth improves. Do the roots of these crops excrete materials useful to each other? Is the mycorrhizal association found in the roots of these tropical legumes and cereals the agent involved in this excretion? Science at the moment is unable to answer these questions: she is only now beginning to investigate them Here we have another instance where the peasants of the East have anticipated and acted upon the solution of one of the problems which Western science is only just beginning to recognize. Whatever may be the reason why crops thrive best when associated in suitable combinations, the fact remains that mixtures generally give better results than monoculture. This is seen in Great Britain in the growth of dredge corn, in mixed crops of wheat and beans, vetches and rye, clover and rye-grass, and in intensive vegetable growing under glass. The produce raised under Dutch lights has noticeably increased since the mixed cropping of the Chinese vegetable growers of Australia has been copied. (Mr. F. A. Secrett was, I believe, the first to introduce this system on a large scale into Great Britain. He informed me that he saw it for the first time at Melbourne.)

A balance between live stock and crops is always maintained. Although crops are generally more important than animals in Eastern agriculture, we seldom or never find crops without animals. This is because oxen are required for cultivation and buffaloes for milk. (The buffalo is the milch cow of the Orient and is capable not only of useful labour in the cultivation of rice, but also of living and producing large quantities of rich milk on a diet on which the best dairy cows of Europe and America would starve. The acclimatization of the Indian buffalo in the villages of the Tropics--Africa, Central America, the West Indies in particular--would do much to improve the fertility of the soil and the nutrition of the people.)

Nevertheless, the waste products of the animal, as is often the case in other parts of the world, are not always fully utilized for the land. The Chinese have for ages past recognized the importance of the urine of animals and the great value of animal wastes in the preparation of composts. In India far less attention is paid to these wastes and a large portion of the cattle dung available is burnt for fuel. On the other hand, in most Oriental countries human wastes find their way back to the land. In China these are collected for manuring the crops direct. In India they are concentrated on the zone of highly manured land immediately round each village. If the population or a portion of it could be persuaded to use a more distant zone for a few years, the area of village lands under intensive agriculture could at least be doubled. Here is an opportunity for the new system of government in India to raise production without the expenditure of a single rupee. In India there are 500,000 villages each of which is surrounded by a zone of very fertile land which is constantly being over-manured by the habits of the people. If we examine the crops grown on this land we find that the yields are high and the plants are remarkably free from disease. Although half a million examples of the connexion between a fertile soil and a healthy plant exist in India alone, and these natural experiments have been in operation for centuries before experiment stations like Rothamsted were ever thought of, modern agricultural science takes no notice of the results and resolutely refuses to accept them as evidence, largely because they lack the support furnished by the higher mathematics. They also dispose of one of the ideas of the disciples of Rudolph Steiner, who argue that the use of human wastes in agriculture is harmful.

Leguminous plants are common. Although it was not till 1888, after a protracted controversy lasting thirty years, that Western science finally accepted as proved the important part played by pulse crops in enriching the soil, centuries of experience had taught the peasants of the East the same lesson. The leguminous crop in the rotation is everywhere one of their old fixed practices. In some areas, such as the Indo-Gangetic plain, one of these pulses--the pigeon pea--is also made use of as a subsoil cultivator. The deep spreading root system is used to promote the aeration of the closely packed silt soils, which so closely resemble those of the Holland Division of Lincolnshire in Great Britain.

Cultivation is generally superficial and is carried out by wooden ploughs furnished with an iron point. Soil-inverting ploughs, as used in the West for the destruction of weeds, have never been designed by Eastern peoples. The reasons for this appear to be two: (1) soil inversion for the destruction of weeds is not necessary in a hot climate where the same work is done by the sun for nothing; (2) the preservation of the level of the fields is essential for surface drainage, for preventing local waterlogging, and for irrigation. Another reason for this surface cultivation has recently been pointed out. The store of nitrogen in the soil in the form of organic matter has to be carefully conserved: it is part of the cultivator's working capital. Too much cultivation and deep ploughing would oxidize this reserve and the balance of soil fertility would soon be destroyed.

Rice is grown whenever possible. By far the most important crop in the East is rice. In India, as has already been pointed out, the production of rice exceeds that of any two food crops put together. Whenever the soil and water supply permit, rice is invariably grown. A study of this crop is illuminating. At first sight rice appears to contradict one of the great principles of the agricultural science of the Occident, namely, the dependence of cereals on nitrogenous manures. Large crops of rice are produced in many parts of India on the same land year after year without the addition of any manure whatever. The rice fields of the country export paddy in large quantities to the centres of population or abroad, but there is no corresponding import of combined nitrogen.

Taking Burma as an example of an area exporting rice beyond seas, during the twenty years ending 1924, about 25,000,000 tons of paddy have been exported from a tract roughly 10,000,000 acres in area. As unhusked rice contains about 1.2 per cent. of nitrogen the amount of this element, shipped overseas during twenty years or destroyed in the burning of the husk, is in the neighbourhood of 300,000 tons. As this constant drain of nitrogen is not made up for by the import of manure, we should expect to find a gradual loss of fertility. Nevertheless, this does not take place either in Burma or in Bengal, where rice has been grown on the same land year after year for centuries. Clearly the soil must obtain fresh supplies of nitrogen from somewhere, otherwise the crop would cease to grow. The only likely source is fixation from the atmosphere, probably in the submerged algal film on the surface of the mud. This is one of the problems of tropical agriculture which is now being investigated.

Where does the rice crop obtain its nitrogen? One source in all probability is fixation from the atmosphere in the submerged algal film
on the surface of the mud. Another is the rice nursery itself, where the seedlings are raised on land heavily manured with cattle dung. Large quantities of nitrogen and other nutrients are stored in the seedling itself; this at transplanting time contains a veritable arsenal of reserves of all kinds which carry the plant successfully through this process and probably also furnish some of the nitrogen needed during subsequent growth. The manuring of the rice seedling illustrates a very general principle in agriculture, namely, the importance of starting a crop in a really fertile soil and so arranging matters that the plant can absorb a great deal of what it needs as early as possible in its development.

There is an adequate supply of labour. Labour is everywhere abundant, as would naturally follow from the great density of the rural population.

Indeed, in India it is so great that if the leisure time of the cultivators and their cattle for a single year could be calculated as money at the local rates a perfectly colossal figure would be obtained. This leisure, however, is not altogether wasted. It enables the cultivators and their oxen to recover from the periods of intensive work which precede the sowing of the crops and which are needed at harvest time. At these periods time is everything: everybody works from sunrise to sunset. The preparation of the land and the sowing of the crops need the greatest care and skill; the work must be completed in a very short time so that a large labour force is essential.

It will be observed that in this peasant agriculture the great pressure of population on the soil results in poverty, most marked where, as in India, extensive methods are used on small-holdings which really need intensive farming. It is amazing that in spite of this unfavourable factor soil fertility should have been preserved for centuries: this is because natural means have been used and not artificial manures. The crops are able to withstand the inroads of insects and fungi without a thin film of protective poison.

THE AGRICULTURAL METHODS OF THE OCCIDENT

If we take a wide survey of the contribution which is being made by the fields of the West, we find that they are engaged in trying to satisfy no less than three hungers: (1) the local hunger of the rural population, including the live stock; (2) the hunger of the growing urban areas, the population of which is unproductive from the point of view of soil fertility; and (3) the hunger of the machine avid for a constant stream of the raw materials required for manufacture. The urban population during the last century has grown out of all knowledge; the needs of the machine increase as it becomes more and more efficient; falling profits are met by increasing the output of manufactured articles. All this adds to the burden on the land and to the calls on its fertility. It will not be without interest to analyse critically the agriculture of the West and see how it is fitting itself for its growing task. This can be done by examining its main characteristics. These are as follows:

The holding tends to increase in size. There is a great variation in the size of the agricultural holdings of the West from the small family units of France and Switzerland to the immense collective farms of Russia and the spacious ranches of the United States and Argentina. Side by side with this growth in the size of the farm is the diminution of the number of men per square mile. In Canada, for example, the number of workers per 1,000 acres of cropped land fell from 26 in 1911 to 16 in 1926. Since these data were published the size of the working population has shrunk still further. This state of things has arisen from the scarcity and dearness of labour which has naturally led to the study of labour-saving devices.

Monoculture is the rule. Almost everywhere crops are grown in pure culture. Except in temporary leys, mixed crops are rare. On the rich prairie lands of North America even rotations are unknown: crops of wheat follow one another and no attempt is made to convert the straw into humus by means of the urine and dung of cattle. The straw is a tiresome encumbrance and is burnt off annually.

The machine is rapidly replacing the animal. Increasing mechanization is one of the main features of Western agriculture. Whenever a machine can be invented which saves human or animal labour its spread is rapid. Engines and motors of various kinds are the rule everywhere. The electrification of agriculture is beginning. The inevitable march of the combine harvester in all the wheat-producing areas of the world is one of the latest examples of the mechanization of the agriculture of the West. Cultivation tends to be quicker and deeper. There is a growing feeling that the more and the deeper the soil is stirred the better will be the crop. The invention of the gyrotiller, a heavy and expensive soil churn, is one of the answers to this demand. The slaves of the Roman Empire have been replaced by mechanical slaves. The replacement of the horse and the ox by the internal combustion engine and the electric motor is, however, attended by one great disadvantage. These machines do not void urine and dung and so contribute nothing to the maintenance of soil fertility. In this sense the slaves of Western agriculture are less efficient than those of ancient Rome.

Artificial manures are widely used. The feature of the manuring of the West is the use of artificial manures. The factories engaged during the Great War in the fixation of atmospheric nitrogen for the manufacture of explosives had to find other markets, the use of nitrogenous fertilizers in agriculture increased, until to-day the majority of farmers and market gardeners base their manurial programme on the cheapest forms of nitrogen (N), phosphorus (P), and potassium (K) on the market. What may be conveniently described as the NPK mentality dominates farming alike in the experimental stations and the country-side. Vested interests, entrenched in time of national emergency, have gained a stranglehold.

Artificial manures involve less labour and less trouble than farm-yard manure. The tractor is superior to the horse in power and in speed of work: it needs no food and no expensive care during its long hours of rest. These two agencies have made it easier to run a farm. A satisfactory profit and loss account has been obtained. For the moment farming has been made to pay. But there is another side to this picture. These chemicals and these machines can do nothing to keep the soil in good heart. By their use the processes of growth can never be balanced by the processes of decay. All that they can accomplish is the transfer of the soil's capital to current account. That this is so will be much clearer when the attempts now being made to farm without any animals at all march to their inevitable failure.

Diseases are on the increase. With the spread of artificials and the exhaustion of the original supplies of humus, carried by every fertile soil, there has been a corresponding increase in the diseases of crops and of the animals which feed on them. If the spread of foot-and-mouth disease in Europe and its comparative insignificance among well fed animals in the East are compared, or if the comparison is made between certain areas in Europe, the conclusion is inevitable that there must be an intimate connexion between faulty methods of agriculture and animal disease. In crops like potatoes and fruit, the use of the poison spray has closely followed the reduction in the supplies of farm-yard manure and the diminution of fertility.

Food preservation processes are also on the increase. A feature of the agriculture of the West is the development of food preservation processes by which the journey of products like meat, milk, vegetables, and fruit between the soil and the stomach is prolonged. This is done by freezing, by the use of carbon dioxide, by drying, and by canning. Although food is preserved for a time in this way, what is the effect of these processes on the health of the community during a period of, say, twenty-five years? Is it possible to preserve the first freshness of food? If so then science will have made a very real contribution.

Science has been called in to help production. Another of the features of the agriculture of the West is the development of agricultural science. Efforts have been made to enlist the help of a number of separate sciences in studying the problems of agriculture and in increasing the production of the soil. This has entailed the foundation of numerous experiment stations which every year pour out a large volume of advice in the shape of printed matter.

These mushroom ideas of agriculture are failing; mother earth deprived of her manurial rights is in revolt; the land is going on strike; the fertility of the soil is declining. An examination of the areas which feed the population and the machines of a country like Great Britain leaves no doubt that the soil is no longer able to stand the strain. Soil fertility is rapidly diminishing, particularly in the United States, Canada, Africa, Australia, and New Zealand. In Great Britain itself real farming has already been given up except on the best lands. The loss of fertility all over the world is indicated by the growing menace of soil erosion. The seriousness of the situation is proved by the attention now being paid to this matter in the press and by the various Administrations. In the United States, for example, the whole resources of government are being mobilized to save what is left of the good earth.

The agricultural record has been briefly reviewed from the standpoint of soil fertility. The main characteristics of the various methods of agriculture have been summarized. The most significant of these are the operations of Nature as seen in the forest. There the fullest use is made of sunlight and rainfall in raising heavy crops of produce and at the same time not only maintaining fertility but actually building up large reserves of humus. The peasants of China, who pay great attention to the return of all wastes to the land, come nearest to the ideal set by Nature. They have maintained a large population on the land without any falling off in fertility. The agriculture of ancient Rome failed because it was unable to maintain the soil in a fertile condition. The farmers of the West are repeating the mistakes made by Imperial Rome. The soils of the Roman Empire, however, were only called upon to assuage the hunger of a relatively small population. The demands of the machine were then almost non-existent. In the West there are relatively more stomachs to fill while the growing hunger of the machine is an additional burden on the soil. The Roman Empire lasted for eleven centuries. How long will the supremacy of the West endure? The answer depends on the wisdom and courage of the population in dealing with the things that matter. Can mankind regulate its affairs so that its chief possession--the fertility of the soil--is preserved? On the answer to this question the future of civilization depends.

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PART I THE PART PLAYED BY SOIL FERTILITY IN AGRICULTURE

CHAPTER II

THE NATURE OF SOIL FERTILITY

What is this soil fertility? What exactly does it mean? How does it affect the soil, the crop, and the animal? How can we best investigate it? An attempt will be made in this chapter to answer these questions and to show why soil fertility must be the basis of any permanent system of agriculture.

The nature of soil fertility can only be understood if it is considered in relation to Nature's round. In this study we must at the outset emancipate ourselves from the conventional approach to agricultural problems by means of the separate sciences and above all from the statistical consideration of the evidence afforded by the ordinary field experiment. Instead of breaking up the subject into fragments and studying agriculture in piecemeal fashion by the analytical methods of science, appropriate only to the discovery of new facts, we must adopt a synthetic approach and look at the wheel of life as one great subject and not as if it were a patchwork of unrelated things.

All the phases of the life cycle are closely connected; all are integral to Nature's activity; all are equally important; none can be omitted. We have therefore to study soil fertility in relation to a natural working system and to adopt methods of investigation in strict relation to such a subject. We need not strive after quantitative results: the qualitative will often serve. We must look at soil fertility as we would study a business where the profit and loss account must be taken along with the balance-sheet, the standing of the concern, and the method of management. It is the 'altogetherness' which matters in business, not some particular transaction or the profit or loss of the current year. So it is with soil fertility. We have to consider the wood, not the individual trees.

The wheel of life is made up of two processes--growth and decay. The one is the counterpart of the other.

Let us first consider growth. The soil yields crops; these form the food of animals: crops and animals are taken up into the human body and are digested there. The perfectly grown, normal, vigorous human being is the highest natural development known to us. There is no break in the chain from soil to man; this section of the wheel of life is uninterrupted throughout; it is also an integration; each step depends on the last. It must therefore be studied as a working whole.

The energy for the machinery of growth is derived from the sun; the chlorophyll in the green leaf is the mechanism by which this energy is intercepted; the plant is thereby enabled to manufacture food--to synthesize carbohydrates and proteins from the water and other substances taken up by the roots and the carbon dioxide of the atmosphere. The efficiency of the green leaf is therefore of supreme importance; on it depends the food supply of this planet, our well-being, and our activities. There is no alternative source of nutriment. Without sunlight and the green leaf our industries, our trade, and our possessions would soon be useless.

The chief factors on which the work of the green leaf depends are the condition of the soil and its relation to the roots of the plant. The plant and the soil come into gear by means of the root system in two ways--by the root hairs and by the mycorrhizal association. The first condition for this gearing is that the internal surface of the soil--the pore space--shall be as large as possible throughout the life of the crop. It is on the walls of this pore space, which are covered with thin water films, that the essential activities of the soil take place. The soil population, consisting mainly of bacteria, fungi and protozoa, carry on their life histories in these water films.

The contact between the soil and the plant which is best understood takes place by means of the root hairs. These are prolongations of the outer layer of cells of the young root. Their duty is to absorb from the thin films of moisture on the walls of the pore space the water and dissolved salts needed for the work of the green leaves: no actual food can reach the plant in this way, only simple things which are needed by the green leaf to synthesize food. The activities of the pore space depend on respiration for which adequate quantities of oxygen are essential. A corresponding amount of carbon dioxide is the natural by-product. To maintain the oxygen supply and to reduce the amount of carbon dioxide, the pore spaces must be kept in contact with the atmosphere. The soil must be ventilated. Hence the importance of cultivation.

As most of the soil organisms possess no chlorophyll, and, moreover, have to work in the dark, they must be supplied with energy. This is obtained by the oxidation of humus--the name given to a complex residue of partly oxidized vegetable and animal matter together with the substances synthesized by the fungi and bacteria which break down these wastes. This humus also helps to provide the cement which enables the minute mineral soil particles to aggregate into larger compound particles and so maintain the pore space. If the soil is deficient in humus, the volume of the pore space is reduced; the aeration of the soil is impeded; there is insufficient organic matter for the soil population; the machinery of the soil runs down; the supply of oxygen, water, and dissolved salts needed by the root hairs is reduced; the synthesis of carbohydrates and proteins in the green leaf proceeds at a lower tempo; growth is affected. Humus is therefore an essential material for the soil if the first phase of the life cycle is to function.

There is another reason why humus is important. Its presence in the soil is an essential condition for the proper functioning of the second contact between soil and plant--the mycorrhizal relationship. By means of this connexion certain soil fungi, which live on humus, are able to invade the living cells of the young roots and establish an intimate relation with the plant, the details of which symbiosis are still being investigated and discussed. Soil fungus and plant cells live together in closer partnership than the algal and fungous constituents of the lichen do. How the fungus benefits has yet to be determined. How the plant profits is easier to understand. If a suitable preparation of such roots is examined under the microscope, all stages in the digestion of the fungous mycelium can be seen. At the end of the partnership the root consumes the fungus and in this manner is able to absorb the carbohydrates and proteins which the fungus obtains partly from the humus in the soil. The mycorrhizal association therefore is the living bridge by which a fertile soil (one rich in humus) and the crop are directly connected and by which food materials ready for immediate use can be transferred from soil to plant. How this association influences the work of the green leaf is one of the most interesting problems science has now to investigate. Is the effective synthesis of carbohydrates and proteins in the green leaf dependent on the digestion products of these soil fungi? It is more than probable that this must prove to be the case. Are these digestion products at the root of disease resistance and quality? It would appear so. If this is the case it would follow that on the efficiency of this mycorrhizal association the health and well-being of mankind must depend.

In a fertile soil the soil and the plant come into gear in two ways simultaneously. In establishing and maintaining these contacts humus is essential. It is therefore a key material in the life cycle. Without this substance the wheel of life cannot function effectively.

The processes of decay which round off and complete the wheel of life can be seen in operation on the floor of any woodland. This has already been discussed. It has been shown how the mixed animal and vegetable wastes are converted into humus and how the forest manures itself.

Such are the essential facts in the wheel of life. Growth on the one side: decay on the other. In Nature's farming a balance is struck and maintained between these two complementary processes. The only man-made systems of agriculture--those to be found in the East--which have stood the test of time have faithfully copied this rule in Nature. It follows therefore that the correct relation between the processes of growth and the processes of decay is the first principle of successful farming. Agriculture must always be balanced. If we speed up growth we must accelerate decay. If, on the other hand, the soil's

reserves are squandered, crop production ceases to be good farming: it becomes
something very different. The farmer is transformed into a bandit.

It is now possible to define more clearly the meaning of soil fertility. It is the condition of a soil rich in humus in which the growth processes proceed rapidly, smoothly, and efficiently. The term therefore connotes such things as abundance, high quality, and resistance to disease. A soil which grows to perfection a wheat crop--the food of man--is described fertile. A pasture on which meat and milk of the first class are produced falls into the same category. An area under market-garden crops on which vegetables of the highest quality are raised has reached the peak as regards fertility.

Why does soil fertility so markedly influence the soil, the plant, and the animal? By virtue of the humus it contains. The nature and properties of this substance as well as the products of its decomposition are therefore important. These matters must now be considered.

What is humus? A reply to this question has been rendered easier by the appearance in 1938 of the second edition of Waksman's admirable monograph on humus in which the results of no less than 1311 original papers have been reduced to order. Waksman defines humus as

'a complex aggregate of brown to dark-coloured amorphous substances which have originated during the decomposition of plant and animal residues by micro-organisms, under aerobic and anaerobic conditions, usually in soils, composts, peat bogs, and water basins. Chemically, humus consists of various constituents of the original plant material resistant to further decomposition; of substances undergoing decomposition; of complexes resulting from decomposition either by processes of hydrolysis or by oxidation and reduction; and of various compounds synthesized by micro-organisms. Humus is a natural body; it is a composite entity, just as are plant, animal, and microbial substances; it is even much more complex chemically, since all these materials contribute to its formation. Humus possesses certain specific physical, chemical, and biological properties which make it distinct from other natural organic bodies. Humus, in itself or by interaction with certain inorganic constituents of the soil, forms a complex colloidal system, the different constituents of which are held together by surface forces; this system is adaptable to changing conditions of reaction, moisture, and action by electrolytes. The numerous activities of the soil micro-organisms take place in this system to a large extent.'

Viewed from the standpoint of chemistry and physics humus is therefore not a simple substance: it is made up from a group of very complex organic compounds depending on the nature of the residues from which it is formed, on the conditions under which decomposition takes place, and on the extent to which the processes of decay have proceeded. Humus, therefore, cannot be exactly the same thing everywhere. It is

bound to be a creature of circumstance. Moreover it is alive and teems with a vast range of micro-organisms which derive most of their nutriment from this substratum. Humus in the natural state is dynamic, not static. From the point of view of agriculture, therefore, we are dealing not with simple
dead matter like a sack of sulphate of ammonia, which can be analysed and valued according to its chemical composition, but with a vast organic complex in which an important section of the farmer's invisible labour force--the organisms which carry on the work of the soil--is temporarily housed. Humus, therefore, involves the element of labour; in this respect also it is one of the most important factors on the farm.

It is essential at this point to pay some attention to the manysided properties of humus and to realize how profoundly it differs from a chemical manure. At the moment all over the world field trials--based on mere nitrogen content--are in progress for comparing, on the current crop, dressings of humus and various artificial manures. A mere glance at the properties of humus will show that such field trials are based on a fundamental misconception of what soil fertility implies and are misleading and therefore useless.

The properties of humus have been summed up by Waksman as follows:

1. Humus possesses a dark brown to black colour.

2. Humus is practically insoluble in water, although a part of it may go into colloidal solution in pure water. Humus dissolves to a large extent in dilute alkali solutions, especially on boiling, giving a dark coloured extract; a large part of this extract precipitates when the alkali solution is neutralized by mineral acids.

3. Humus contains a somewhat larger amount of carbon than do plant, animal, and microbial bodies; the carbon content of humus is usually about 55 to 56 per cent., and frequently reaches 58 per cent.

'4. Humus contains considerable nitrogen, usually about 3 to 6 per cent. The nitrogen concentration may be frequently less than this figure; in the case of certain high-moor peats, for example, it may be only 0.5-0.8 per cent. It may also be higher, especially in sub-soils, frequently reaching 10 to 12 per cent.

'5. Humus contains the elements carbon and nitrogen in proportions which are close to 10:1; this is true of many soils and of humus in sea bottoms. This ratio varies considerably with the nature of the humus, the stage of its decomposition, the nature and depth of soil from which it is obtained, the climatic and other environmental conditions under which it is formed.

6. Humus is not in a static, but rather in a dynamic, condition, since it is constantly formed from plant and animal residues and is continuously decomposed further by micro-organisms.

7. Humus serves as a source of energy for the development of various groups of micro-organisms, and during decomposition gives off a continuous stream of carbon dioxide and ammonia.

8. Humus is characterized by a high capacity of base-exchange, of combining with various other soil constituents, of absorbing water, and of swelling, and by other physical and physico-chemical properties which make it a highly valuable constituent of substrates which support plant and animal life.'

To this list of properties must be added the role of humus as a cement in creating and maintaining the compound soil particles so important in the maintenance of tilth.

The effect of humus on the crop is nothing short of profound. The farmers and peasants who live in close touch with Nature can tell by a glance at the crop whether or not the soil is rich in humus. The habit of the plant then develops something approaching personality; the foliage assumes a characteristic set; the leaves acquire the glow of health; the flowers develop depth of colour; the minute morphological characters of the whole of the plant organs become clearer and sharper. Root development is profuse: the active roots exhibit not only turgidity but bloom.

The influence of humus on the plant is not confined to the outward appearance of the various organs. The quality of the produce is also affected. Seeds are better developed, and so yield better crops and also provide live stock with a satisfaction not conferred by the produce of worn-out land. The animals need less food if it comes from fertile soil. Vegetables and fruit grown on land rich in humus are always superior in quality, taste, and keeping power to those raised by other means. The quality of wines, other things being equal, follows the same rule. Almost every villager in countries like France appreciates these points and will talk of them freely without the slightest prompting.

In the case of fodder a very interesting example of the relation between soil fertility and quality has recently been investigated. This was noticed in the meadows of La Crau between Salon and Aries in Provence. Here the fields are irrigated with muddy water, containing finely divided limestone drawn from the Durance, and manured mostly with farm-yard manure. The soils are open and permeable, the land is well drained naturally. All the factors on which soil fertility depends are present together--an open soil with ample organic matter, ample moisture, and the ideal climate for growth. Any grazier who saw these meadows for the first time would at once be impressed by them: a walk through the fields at hay-making would prepare him for the news that it pays the owners of high-quality animals to obtain their roughage from this distant source. Several cuts of hay are produced every year, which enjoy such a reputation for quality that the bales are sent long distances by motor lorry to the various racing stables of France and are even exported to Newmarket. The small stomach of the racehorse needs the very best food possible. This the meadows of La Crau help to produce.

The origin of these irrigated meadows would provide an interesting story. Did they arise as the result of a set of permanent manurial experiments on the Broadbalk model or through the work of some observant local pioneer? I suspect the second alternative will be found to be nearer the truth. A definite answer to this question is desirable because in a recent discussion at Rothamsted, on the relation between a fertile soil and high-quality produce, it was stated that no evidence of such a connexion could be discovered in the literature. The farmers of Provence, however, have supplied it and also a measure of quality in the shape of a satisfactory price. For the present the only way of measuring quality seems to be by selling it. It cannot be weighed and measured by the methods of the laboratory. Nevertheless it exists: moreover it constitutes a very important factor in agriculture. Apparently some of the experiment stations have not yet come to grips with this factor: the farmers have. The sooner therefore that effective liaison is established between these two agencies the better.

The effect of soil fertility on live stock can be observed in the field. As animals live on crops we should naturally expect the character of the plant as regards nutrition to be passed on to stock. This is so. The effect of a fertile soil can at once be seen in the condition of the animals. This is perhaps most easily observed in the bullocks fattened on some of the notable pastures in Great Britain. The animals show a well-developed bloom, the coat and skin look and feel right, the eyes are clear, bright, and lively. The posture of the animal betokens health and well-being. It is not necessary to weigh or measure them. A glance on the part of a successful grazier, or of a butcher accustomed to deal with high-class animals, is sufficient to tell them whether all is well or whether there is something wrong with the soil or the management of the animals or both. The results of a fertile soil and proper methods of management are measured by the prices these animals fetch in the market and the standing of the farmer in these markets. It should be a compulsory item in the training of agricultural investigators to accompany some of the best of our English cattle from the pasture to the market and watch what happens there. They would at once discover that the most fertile pastures produce the best animals, that auctioneers and buyers detect quality instantly, and that such animals find a ready sale and command the best prices. The reputation of the pastures is finally passed on to the butcher and to his clients.

Resistance to insect and fungous disease is also conferred by humus. Perhaps the best examples of this are to be seen in the East. In India, the crops grown on the highly fertile soils round the 500,000 villages suffer remarkably little from pests. This subject is developed at length in a future chapter when the retreat of the crop and of the animal before the parasite is discussed.

Soil fertility not only influences crops and live stock but also the fauna of the locality. This is perhaps most easily seen in the fish of streams which flow through areas of widely differing degrees of fertility. An example of such difference is referred to at the end of Chapter V of Isaac Walton's COMPLEAT ANGLER the following words:

'And so I shall proceed next to tell you, it is certain, that certain fields near Leominster, a town in Herefordshire, are observed to make sheep that graze upon them more fat than the next, and also to bear finer wool; that is to say, that in that year in which they feed in such a particular pasture, they shall yield finer wool than they did that year before they came to feed in it, and coarser again if they shall return to their former pasture; and again return to a finer wool, being fed in the fine wool ground. Which I tell you, that you may the better believe that I am certain, if I catch a trout in one meadow he shall be white and faint, and very likely to be lousy; and as certainly if I catch a trout in the next meadow, he shall be strong and red and lusty and much better meat: trust me, scholar. I have caught many a trout in a particular meadow, that the very shape and enamelled colour of him hath been such as hath joyed me to look on him: and I have then with much pleasure concluded with Solomon, "Everything is beautiful in his season".'

Soil fertility is the condition which results from the operation of Nature's round, from the orderly revolution of the wheel of life, from the adoption and faithful execution of the first principle of agriculture--there must always be a perfect balance between the processes of growth and the processes of decay. The consequences of this condition are a living soil, abundant crops of good quality, and live stock which possess the bloom of health. The key to a fertile soil and a prosperous agriculture is humus.

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CHAPTER III

THE RESTORATION OF FERTILITY

The moment mankind undertook the business of raising crops and breeding animals, the processes of Nature were subjected to interference. Soil fertility was exploited for the growing of food and the production of the raw materials--such as wool, skins, and vegetable fibres--needed for clothing. Up to the dawn of the Industrial Revolution in the West, the losses of humus involved in these agricultural operations were made up either by the return of waste material to the soil or by taking up virgin land.

Where the return of wastes balanced the losses of humus involved in production, systems of agriculture became stabilized and there was no loss of fertility. The example of China has already been quoted. The old mixed farming of a large part of Europe, including Great Britain--characterized by a correct balance between arable and live stock, the conversion of wastes into farmyard manure, methods of sheep folding, and the copious use of the temporary ley--is another instance of the same thing.

The constant exploitation of new areas to replace worn-out land has also gone on for centuries and is still taking place. Sometimes this has involved wars and conquests: at other times nothing more than taking up fresh prairie or forest land wherever this was to be found. A special method is adopted by some primitive tribes. The forest growth is burnt down, the store of humus is converted into crops, the exhausted land is given back to Nature for reafforestation and the building up of a new reserve of humus. In a rough and ready way fertility is maintained. Such shifting cultivation still exists all over the world, but like the taking up of new land is only possible when the population is small and suitable land abundant. This burning process has even been incorporated into permanent systems of agriculture and has proved of great value in rice cultivation in western India. Here the intractable soils of the rice nurseries have to be prepared during the last part of the hot season so that the seedlings are ready for transplanting by the break of the monsoon. This is achieved by covering the nurseries with branches collected from the forest and setting fire to the mass. The heat destroys the colloids, restores the tilth, and makes the manuring and cultivation of the rice nurseries possible.

It is an easy matter to destroy a balanced agriculture. Once the demand for food and raw materials increases and good prices are obtained for the

produce of the soil, the pressure on soil fertility becomes intense. The temptation to convert this fertility into money becomes irresistible. Western agriculture was subjected to this strain by the very rapid developments which followed the invention of the steam-engine, the internal combustion engine, electrically driven motors, and improvements in communications and transport. Factory after factory arose; a demand for labour followed; the urban population increased. All these developments provided new and expanding markets for food and raw materials. These were supplied in three ways--by cashing-in the existing fertility of the whole world, by the use of a temporary substitute for soil fertility in the shape of artificial manures, and by a combination of both methods. The net result has been that agriculture has become unbalanced and therefore unstable.

Let us review briefly the operations of Western agriculture from the point of view of the utilization of wastes in order to discover whether the gap between the losses and gains of humus, now bridged by artificials, can be reduced or abolished altogether. If this is possible, something can be done to restore the balance of agriculture and to make it more stable and therefore more permanent.

Many sources of soil organic matter exist, namely: (1) the roots of crops, weeds, and crop residues which are turned under in the course of cultivation; (2) the algae met with in the surface soil; (3) temporary leys, the turf of worn-out grass land, catch crops, and green-manures; (4) the urine of animals; (5) farmyard manure; (6) the contents of the dustbins of our cities and towns; (7) certain factory wastes which result from the processing of agricultural produce; (8) the wastes of the urban population; (9) water-weeds, including seaweed. These must now be very briefly considered. In later chapters most of these matters will be referred to again and discussed in greater detail.

THE RESIDUES TURNED UNDER IN THE COURSE OF CULTIVATION. It is not always realized that about half of every crop--the root system--remains in the ground at harvest time and thus provides a continuous return of organic matter to the soil.

The weeds and their roots ploughed in during the ordinary course of cultivation add to this supply. When these residues, supplemented by the fixation of nitrogen from the atmosphere, are accompanied by skilful soil management, which safeguards the precious store of humus, crop production can be maintained at a low level without the addition of any manure whatsoever beyond the occasional droppings of live stock and birds. A good example of such a system of farming without manure is to be found in the alluvial soils of the United Provinces in India where the field records of ten centuries prove that the land produces small crops year after year without any falling off in fertility. A perfect balance has been reached between the manurial requirements of the crops harvested and the natural processes which recuperate fertility. The greatest care, however, is taken not to over-cultivate, not to cultivate at the wrong time, or to stimulate the soil processes by chemical manures. Systems of farming such as these supply as it were the base-line for agricultural development. A similar though not so convincing result is provided by the permanent wheat plot at Rothamsted, where this crop has been grown on the same land without manure since 1844. This plot, which has been without manure of any kind since 1839, showed a slow decline in production for the first eighteen years, after which the yield has been practically constant. The reserves of humus in this case left over from the days of mixed farming evidently lasted for nearly twenty years. There are, however, two obvious weaknesses in this experiment. This plot does not represent any system of agriculture, it only speaks for itself. Nothing has been done to prevent earthworms and other animals from bringing in a constant supply of manure, in the shape of their wastes, from the surrounding land. It is much too small to yield a significant result.

Soil algae are a much more important factor in the tropics than in temperate regions. Nevertheless they occur in all soils and often play a part in the maintenance of soil fertility. Towards the end of the rainy season in countries like India a thick algal film occurs on the surface of the soil which immobilizes a large amount of combined nitrogen otherwise likely to be lost by leaching. While this film is forming cultivation is suspended and weeds are allowed to grow. Just before the sowing of the cold weather crops in October the land is thoroughly cultivated, when this easily decomposable and finely divided organic matter, which is rich in nitrogen, is transformed into humus and then into nitrates. How far a similar method can be utilized in colder countries is a matter for investigation. In the East cultivation always fits in with the life-cycle in a remarkable way. In the West cultivation is regarded as an end in itself and not, as it should be, as a factor in the wheel of life. Europe has much to learn from Asia in the cultivation of the soil.

TEMPORARY LEYS, CATCH-CROPS, GREEN-MANURES, AND THE TURF OF WORN-OUT GRASS LAND are perhaps the most important source of humus in Western agriculture. All these crops develop a large root system; the permanent and temporary leys give rise to ample residues of organic matter which accumulate in the surface soil. Green-manures and catch-crops develop a certain amount of soft and easily decomposable tissue. Provided these crops are properly utilized a large addition of new humus can be added to the soil. The efficiency of these methods of maintaining soil fertility could, however, be very greatly increased.

THE URINE OF ANIMALS. The key substance in the manufacture of humus from vegetable wastes is urine--the drainage of the active cells and glands of the animal. It contains in a soluble and balanced form all the nitrogen and minerals, and in all probability the accessory growth-substances as well, needed for the work of the fungi and bacteria which break down the various forms of cellulose--the first step in the synthesis of humus. It carries in all probability every raw material, known and unknown, discovered and undiscovered, needed in the building up of a fertile soil. Much of this vital substance for restoring soil fertility is either wasted or only imperfectly utilized. This fact alone would explain the disintegration of the agriculture of the West.

Although FARM-YARD MANURE has always been one of the principal means of replenishing soil losses, even now the methods by which this substance is prepared are nothing short of deplorable. The making of farm-yard manure is the weakest link in the agriculture of Western countries. For centuries this weakness has been the fundamental fault of Western farming, one completely overlooked by many observers and the great majority of investigators.

DUSTBIN REFUSE. Practically no agricultural use is now being made of the impure cellulose and kitchen wastes which find their way into the urban dustbin. These are mostly buried in controlled tips or burnt.

ANIMAL RESIDUES. A number of wastes connected with the processing of food and some of the raw materials needed in industry are utilized on the land and find a ready market. The animal residues include such materials as dried blood, feathers, greaves, hair waste, hoof and horn, rabbit waste, slaughter-house refuse, and fish waste. There is a brisk demand for most of these substances, as they give good results on the land. The only drawback is the limited supplies available. The organic residues from manufacture consist of damaged oil-cakes, shoddy and tannery waste, of which shoddy, a by-product of the wool industry, is the most important. These two classes of wastes, animal and industrial, are applied to the soil direct and, generally speaking, command much higher prices than would be expected from their content of nitrogen, phosphorus, and potash. This is because the soil is in such urgent need of humus and because the supply falls so far short of the demand. It is probable that a better use for these wastes will be found as raw materials for the compost heaps of the future, where they will act as substitutes for urine in the breaking down of dustbin refuse in localities where the supply of farm-yard manure is restricted.

WATER WEEDS. Little use is made of water weeds in maintaining soil fertility. Perhaps the most useful of these is seaweed, which is thrown up on the beaches in large quantities at certain times of the year and which contains iodine and includes the animal residues needed for converting vegetable wastes into humus. Many of our sea-side resorts could easily manufacture from seaweed and dustbin refuse the vast quantities of humus needed for the farms and market gardens in their neighbourhood and so balance the local agriculture. Little or nothing, however, is being done in this direction. In some cases the seaweed collection on pleasure beaches is taken up by the farmers with good results, but the systematic utilization of seaweed in the compost heap is still a matter for the future. The streams and rivers which carry off the surplus rainfall also contain appreciable quantities of combined nitrogen and minerals in solution. Much of this could be intercepted by the cultivation of suitable plants on the borders of these streams which would furnish large quantities of easily decomposable material for humus manufacture.

THE NIGHT SOIL AND URINE of the population is at present almost completely lost to the land. In urban areas the concentration of the population is the main reason why water-borne sewage systems have developed. The greatest difficulty in the path of the reformer is the absence of sufficient land for dealing with these wastes. In country districts, however, there are no insurmountable obstacles to the utilization of human wastes.

It will be evident that in almost every case the vegetable and animal residues of Western agriculture are either being completely wasted or else imperfectly utilized. A wide gap between the humus used up in crop production and the humus added as manure has naturally developed. This has been filled by chemical manures. The principle followed, based on the Liebig tradition, is that any deficiencies in the soil solution can be made up by the addition of suitable chemicals. This is based on a complete misconception of plant nutrition. It is superficial and fundamentally unsound. It takes no account of the life of the soil, including the mycorrhizal association--the living fungous bridge which connects soil and sap. Artificial manures lead inevitably to artificial nutrition, artificial food, artificial animals, and finally to artificial men and women.

The ease with which crops can be grown with chemicals has made the correct utilization of wastes much more difficult. If a cheap substitute for humus exists why not use it? The answer is twofold. In the first place, chemicals can never be a substitute for humus because Nature has ordained that the soil must live and the mycorrhizal association must be an essential link in plant nutrition. In the second place, the use of such a substitute cannot be cheap because soil fertility--one of the most important assets of any country--is lost; because artificial plants, artificial animals, and artificial men are unhealthy and can only be protected from the parasites, whose duty it is to remove them, by means of poison sprays, vaccines and serums and an expensive system of patent medicines, panel doctors, hospitals, and so forth. When the finance of crop production is considered together with that of the various social services which are needed to repair the consequences of an unsound agriculture, and when it is borne in mind that our greatest possession is a healthy, virile population, the cheapness of artificial manures disappears altogether. In the years to come chemical manures will be considered as one of the greatest follies of the industrial epoch. The teachings of the agricultural economists of this period will be dismissed as superficial.

In the next section of this book the methods by which the agriculture of the West can be reformed and balanced and the use of artificial manures given up will be discussed.

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PART II THE INDORE PROCESS

CHAPTER IV

THE INDORE PROCESS

The Indore Process for the manufacture of humus from vegetable and animal wastes was devised at the Institute of Plant Industry, Indore, Central India, between the years 1924 and 1931. It was named after the Indian State in which it originated, in grateful remembrance of all the Indore Darbar did to make my task in Central India easier and more pleasant.

Although the working out of the actual process only took seven years, the foundations on which it is based occupied me for more than a quarter of a century. Two independent lines of thought and study led up to the final result. One of these concerns the nature of disease and is discussed more fully in Chapter XI under the heading--'The Retreat of the Crop and the Animal before the Parasite'. It was observed in the course of these studies that the maintenance of soil fertility is the real basis of health and of resistance to disease. The various parasites were found to be only secondary matters: their activities resulted from the breakdown of a complex biological system--the soil in its relation to the plant and to the animal--due to improper methods of agriculture, an impoverished soil, or to a combination of both.

The second line of thought arose in the course of nineteen years (1905-24) spent in plant-breeding at Pusa, when it was gradually realized that the full possibilities of the improvement of the variety can only be achieved when the soil in which the new types are grown is provided with an adequate supply of humus. Improved varieties by themselves could be relied upon to give an increased yield in the neighbourhood of 10 per cent.: improved varieties plus better soil conditions were found to produce an increment up to 100 per cent. or even more. As an addition of even 10 per cent. to the yield would ultimately impose a severe strain on the frail fertility reserves of the soils of India and would gradually lead to their impoverishment, plant-breeding to achieve any permanent success would have to include a continuous addition to the humus content of the small fields of the Indian cultivators. The real problem was not the improvement of the variety but how simultaneously to make the variety and the soil more efficient.

By about the year 1918 these two hitherto independent approaches to the problems of crop production--by way of pathology and by way of plant-breeding--began to coalesce. It became clearer and clearer that agricultural research itself was involved in the problem; that the organization was responsible for the failure to recognize the things that matter in agriculture and would therefore have to be reformed; the separation of work on crops into such compartments as plant-breeding, mycology, entomology, and so forth, would have to be given up; the plant would have to be studied in relation to the soil on the one hand and to the agricultural practices of the locality on the other. An approach to the problems of crop production on such a wide front was obviously impossible in a research institute like Pusa in which the work on crops was divided into no less than six separate sections. The working out of a method of manufacturing humus from waste products and a study of the reaction of the crop to improved soil conditions would encroach on the work of practically every section of the Institute. As no progress has ever been made in science without complete freedom, the only way of studying soil fertility as one subject appeared to be to found a new institute in which the plant would be the centre of the subject and where science and practice could be brought to bear on the problem without any consideration of the existing organization of agricultural research. Thanks to the support of a group of Central Indian States and a large grant from the Indian Central Cotton Committee, the Institute of Plant Industry was founded at Indore in 1924. Central India was selected as the home of this new research centre for two reasons: (1) the offer on a 99 years' lease of an area of 300 acres of suitable land by the Indore Darbar, and (2) the absence in the Central India Agency of any organized system of agricultural research such as had been established throughout

British India. This tract therefore provided the land on the one hand and freedom from interference on the other for the working out of a new approach, based on the humus content of the soil, to the problems underlying crop production. (An account of the organization of the Institute of Plant Industry was published as THE APPLICATION OF SCIENCE TO CROP-PRODUCTION by the Oxford University Press in 1929.)

The work at Indore accomplished two things: (1) the obsolete character of the present-day organization of agricultural research was demonstrated; (2) a practical method of manufacturing humus was devised.

The Indore Process was first described in detail in 1931 in Chapter IV of THE WASTE PRODUCTS OF AGRICULTURE. Since that date the method has been taken up by most of the plantation industries and also on many farms and gardens all over the world. In the course of this work nothing has been added to the two main principles underlying the process, namely, (1) the admixture of vegetable and animal wastes with a base for neutralizing acidity, and (2) the management of the mass so that the micro-organisms which do the work can function in the most effective manner. A number of minor changes in working have, however, been suggested. Some of these have proved advantageous in increasing the output. In the following account the original description has been followed, but all useful improvements have been incorporated: the technique has been brought up to date.

THE RAW MATERIALS NEEDED

1. VEGETABLE WASTES. In temperate countries like Great Britain these

include--straw, chaff, damaged hay and clover, hedge and bank trimmings, weeds including sea-and water-weeds, prunings, hop-vine and hop-string, potato haulm, market-garden residues including those of the greenhouse, bracken, fallen leaves, sawdust, and wood shavings. A limited amount of other vegetable material like the husks of cotton seed, cacao, and ground nuts as well as banana stalks are also available near some of the large cities.

In the tropics and sub-tropics the vegetable wastes consist of very similar materials including the vegetation of waste areas, grass, plants grown for shade and green-manure, sugar-cane leaves and stumps, all crop residues not consumed by live stock, cotton stalks, weeds, sawdust and wood shavings, and plants grown for providing compostable material on the borders of fields, roadsides, and any vacant corners available.

A continuous supply of mixed dry vegetable wastes throughout the year, in a proper state of division, is the chief factor in the process. The ideal chemical composition of these materials should be such that, after being used as bedding for live stock, the carbon: nitrogen ratio is in the neighbourhood of 33:1. The material should also be in such a physical condition that the fungi and bacteria can obtain ready access to and break down the tissues without delay. The bark, which is the natural protection of the celluloses and lignins against the inroads of fungi,
must first be destroyed. This is the reason why all woody materials--such as cotton and pigeon-pea stalks--were always laid on the roads at Indore and crushed by the traffic into a fine state of division before composting.

All over the world one of the first objections to the adoption of the Indore Process is that there is nothing worth composting or only small supplies of such material. In practically all such cases any shortage of wastes has soon been met by a more effective use of the land and by actually growing plants for composting on every possible square foot of soil. If Nature's way of using sunlight to the full in the virgin forest is compared with that on the average farm or on the average tea and rubber estate, it will be seen what leeway can be made up in growing suitable material for making humus. Sometimes the objection is heard that all this will cost too much. The answer is provided by the dust-bowls of North America. The soil must have its manurial rights or farming dies.

2. ANIMAL RESIDUES. The animal residues ordinarily available all over the world are much the same--the urine and dung of live stock, the droppings of poultry, kitchen waste including bones. Where no live stock is kept and animal residues are not available, substitutes such as dried blood, slaughter-house refuse, powdered hoof and horn, fish manure, and so forth can be employed. The waste products of the animal in some form or another are essential if real humus is to be made for the two following reasons.

(a) The verdict given by mother earth between humus made with animal residues and humus made with chemical activators like calcium cyanamide and the various salts of ammonia has always been in favour of the former.

One has only to feel and smell a handful of compost made by these two methods to understand the plant's preference for humus made with animal residues. The one is soft to the feel with the smell of rich woodland earth: the other is often harsh to the touch with a sour odour. Sometimes when the two samples of humus made from similar vegetable wastes are analysed, the better report is obtained by the compost made with chemical activators. When, however, they are applied to the soil the plant speedily reverses the verdict of the laboratory. Dr. Rayner refers to this conflict between mother earth and the analyst, in the case of some composts suitable for forestry nurseries, in the following words:

'Full chemical analyses are now available for a number of these composts, and it is not without interest to recall that in the initial stages of the work a competent critic reported on one of them--since proved to be among the most effective a basis of comparative analysis, as "an organic manure of comparatively little value"; while another--since proved least successful of all those tested--was approved as a "first-class organic manure".'

The activator used in the first case was dried blood, in the second case an ammonium salt.

(b) No permanent or effective system of agriculture has ever been devised without the animal. Many attempts have been made, but sooner or later

they break down. The replacement of live stock by artificials is always followed by disease the moment the original store of soil fertility is exhausted.

Where live stock is maintained the collection of their waste products--urine and dung--in the most effective manner is important.

At Indore the work-cattle were kept in well-ventilated sheds with earthen floors and were bedded down daily with mixed vegetable wastes including about 5 per cent. by volume of hard resistant material such as wood shavings and sawdust. The cattle slept on this bedding during the night when it was still further broken up and impregnated with urine. Next morning the soiled bedding and cattle dung were removed to the pits for composting; the earthen floor was then swept clean and all wet places were covered with new earth, after scraping out the very wet patches. In this way all the urine of the animals was absorbed; all smell in the cattle sheds was avoided, and the breeding of flies in the earth underneath the animals was entirely prevented. A new layer of bedding for the next day was then laid.

Every three months the earth under the cattle was changed, the urine-impregnated soil was broken up in a mortar mill and stored under cover near the compost pits. This urine earth, mixed with any wood ashes available, served as a combined activator and base in composting.

In the tropics, where there is abundance of labour, no difficulty will be experienced in copying the Indore plan. All the urine can be absorbed:
all the soiled bedding can be used in the compost pits every morning.

In countries like Great Britain and North America, where labour is both scarce and dear, objection will at once be raised to the Indore plan. Concrete or pitched floors are here the rule. The valuable urine and dung are often removed to the drains by a water spray. In such cases, however, the indispensable urine could either be absorbed on the floors themselves by the addition to the bedding of substances like peat and sawdust mixed with a little earth, or the urine could be directed into small bricked pits just outside the building, filled with any suitable absorbent which is periodically removed and renewed. In this way liquid manure tanks can be avoided. At all costs the urine must be used for composting.

3. BASES FOR NEUTRALIZING EXCESSIVE ACIDITY. In the manufacture of humus the fermenting mixture soon becomes acid in reaction. This acidity must be neutralized, otherwise the work of the microorganisms cannot proceed at the requisite speed. A base is therefore necessary. Where the carbonates of calcium or potassium are available in the form of powdered chalk or limestone, or wood ashes, these materials either alone, together, or mixed with earth, provide a convenient base for maintaining the general reaction within the optimum range (pH 7.0 to 8.0) needed by the microorganisms which break down cellulose. Where wood ashes, limestone, or chalk are not

available, earth can be used by itself. Slaked lime can also be employed, but it is not so suitable as the carbonate. Quicklime is much too fierce a base.

4. WATER AND AIR. Water is needed during the whole of the period during which humus is being made. Abundant aeration is also essential during the early stages. If too much water is used the aeration of the mass is impeded, the fermentation stops and may soon become anaerobic too soon. If too little water is employed the activities of the micro-organisms slow down and then cease. The ideal condition is for the moisture content of the mass to be maintained at about half saturation during the early stages, as near as possible to the condition of a pressed-out sponge. Simple as all this sounds, it is by no means easy in practice

simultaneously to maintain the moisture content and the aeration of a compost heap so that the micro-organisms can carry out their work effectively. The tendency almost everywhere is to get the mass too sodden.

The simplest and most effective method of providing water and oxygen together is whenever possible to use the rainfall--which is a saturated solution of oxygen--and always to keep the fermenting mass open at the beginning so that atmospheric air can enter and the carbon dioxide produced can escape.

After the preliminary fungous stage is completed and the vegetable wastes have broken down sufficiently to be dealt with by bacteria, the synthesis of humus proceeds under anaerobic conditions when no special measures for the aeration of the dense mass are either possible or necessary.

PITS VERSUS HEAPS

Two methods of converting the above wastes into humus are in common use. Pits or heaps can be employed.

Where the fermenting mass is liable to dry out or to cool very rapidly, the manufacture should take place in shallow pits. A considerable saving of water then results. The temperature of the mass tends to remain high and uniform. Sometimes, however, composting in pits is disadvantageous on account of water-logging by storm water, by heavy rain, and by the rise of the ground-water from below. All these result in a wet sodden mass in which an adequate supply of air is out of the question. To obviate such water-logging the composting pits are: (1) surrounded by a catch-drain to cut off surface water; (2) protected by a thatched roof where the rainfall is high and heavy bursts of monsoon rain are the rule; or (3) provided with soakaways at suitable points combined with a slight slope of the floors of the pit towards the drainage corner. Where there is a pronounced rise in the water-table during the rainy season, care must be taken, in siting the pits, that they are so placed that there is no invasion of water from below.

To save the expense of digging pits and to use up sites where excavation is out of the question, composting in heaps is practiced. A great deal can be done to increase the efficiency of the heap by protecting the composting area from storm water by means of catch-drains and by suitable shelter from wind, which often prevents all fermentation on the more exposed sides of the heap. In temperate climates heaps should always face the south, and wherever possible should be made in front of a south wall and be protected from wind on the east and west. The effect of heavy rain in slowing down fermentation can be reduced by increasing the size of the heap as much as possible. Large heaps always do better than small ones.

In localities of high monsoon rainfall like Assam and Ceylon, there is a definite tendency to provide the heap or the pit with a grass roof so that the fermentation can proceed at an even rate and so that the annual output is not interfered with by temporary water-logging. After a year or two of service the roof itself is composted. In Great Britain thatched hurdles can be used.

CHARGING THE HEAPS OR PITS

A convenient size for the compost pits (where the annual output is in the neighbourhood of 1,000 tons) is 30 feet by 14 feet and 3 feet deep with sloping sides. The depth is the most important dimension on account of the aeration factor. Air percolates the fermenting mass to a depth of about 18 to 24 inches only, so for a height of 36 inches extra aeration must be provided. This is arranged by means of vertical vents, every 4 feet, made by a light crowbar as each section of the pit is charged.

Charging a pit 30 feet long takes place in six sections each 5 feet wide. The first section, however, is left vacant to allow of the contents being turned. The second section is first charged. A layer of vegetable wastes about 6 inches deep is laid across the pit to a width of 5 feet. This is followed by a layer of soiled bedding or farm-yard manure 2 inches in thickness. The layer of manure is then well sprinkled with a mixture of

urine earth and wood ashes or with earth alone, care being taken not to add more than a thin film of about one-eighth of an inch in thickness. If too much is added aeration will be impeded. The sandwich is then watered where necessary with a hose fitted with a rose for breaking up the spray. The charging and watering process is then continued as before until the total height of the section reaches 5 feet. Three vertical aeration vents, about 4 inches in diameter, are then made in the mass by working a crowbar from side to side. The first vent is in the centre, the other two midway between the centre and the sides. As the pit is 14 feet wide and there are three vents, these will be 3 feet 6 inches apart. The next section of the pit (5 feet wide) is then built up close to the first and watered as before. When five sections are completed the pit is filled. The advantages of filling a pit or making a heap in sections to the full height of 5 feet are: (1) fermentation begins at once in each section and no time is lost; (2) no trampling of the mass takes place; (3) aeration vents can be made in each completed section without standing on the mixture.

In dry climates each day's contribution to the pit should again be lightly watered in the evening and the watering repeated the next morning. In this way the first watering at the time of charge is added in three portions--one at the actual time of charging, in the evening after charging is completed and again the next morning after an interval of twelve hours. The object of this procedure is to give the mass the necessary time to absorb the water.

The total amount of water that should be added at the beginning of fermentation depends on the nature of the material, on the climate and on the rainfall. Watering as a rule is unnecessary in Great Britain. If the material contains about a quarter by volume of fresh greenstuff the amount of water needed can be considerably reduced. In rainy weather when everything is on the damp side no water at all is needed. Correct watering is a matter of local circumstances and of individual judgement. At no period should the mass be wet: at no period should the pit be allowed to dry out completely. At the Iceni Nurseries in South Lincolnshire in Great Britain, where the annual rainfall is about 24 inches and a good deal of fresh green market-garden refuse is composted, watering the heaps at all stages is unnecessary. At Indore in Central India where the rainfall was about 50 inches, which fell in about four months, watering was always essential except during the actual rainy season. These two examples prove that no general rule can ever be laid down as to the amount of water to be added in composting. The amount depends on circumstances. The water needed at Indore was from 200 to 300 gallons for each cubic yard of finished humus.

As each section of the pit is completed, everything is ready for the development of an active fungous growth, the first stage in the manufacture of humus. It is essential to initiate this growth as quickly as possible and then to maintain it. As a rule it is well established by the second or third day after charging. Soon after the first appearance of fungous growth the mass begins to shrink and in a few days will just fill the pit, the depth being reduced to about 36 inches.

Two things must be carefully watched for and prevented during the first phase: (1) the establishment of anaerobic conditions caused generally by over-watering or by want of attention to the details of charging; it is at once indicated by smell and by the appearance of flies attempting to breed in the mass; when this occurs the pit should be turned at once; (2) fermentation may slow down for want of water. In such cases the mass should be watered. Experience will soon teach what amount of water is needed at the time of charge.

TURNING THE COMPOST

To ensure uniform mixture and decay and to provide the necessary amount of water and air for the completion of the aerobic phase it is necessary to turn the material twice.

FIRST TURN. The first turn should take place between 2 and 3 weeks after charging. The vacant space, about 5 feet wide, at the end of the pit allows the mass to be conveniently turned from one end by means of a pitchfork. The fermenting material is piled up loosely against the vacant end of the pit, care being taken to turn the unaltered layer in contact with the air into the middle of the new heap. As the turning takes place, the mass is watered, if necessary, as at the time of charging, care being taken to make the material moist but not sodden with water. The aim should be to provide the mass with sufficient moisture to carry on the fermentation to the second turn. To achieve this sufficient time must be given for the absorption of water. The best way is to proceed as at the time of charging and add any water needed in two stages--as the turning is being done and again next morning. Another series of vertical air vents 3 feet 6 inches apart should be made with a crowbar as the new heap is being made.

SECOND TURN. About five weeks after charge the material is turned a second time but in the reverse direction. By this time the fungous stage will be almost over, the mass will be darkening in colour and the material will be showing marked signs of breaking down. From now onwards bacteria take an increasing share in humus manufacture and the process becomes anaerobic. The second turn is a convenient opportunity for supplying sufficient water for completing the fermentation. This should be added during the actual turning and again the next morning to bring the moisture content to the ideal condition--that of a pressed-out sponge. It will be observed as manufacture proceeds that the mass crumbles and that less and less difficulty occurs in keeping the material moist. This is due to two things: (1) less water is needed in the fermentation; (2) the absorptive and water-holding power of the mass rapidly increase as the stage of finished humus is approached.

Soon after the second turn the ripening process begins. It is during this period that the fixation of atmospheric nitrogen takes place. Under favourable circumstances as much as 25 per cent. Of additional free nitrogen may be secured from the atmosphere.

The activity of the various micro-organisms which synthesize humus can most easily be followed from the temperature records. A very high temperature, about 65 degrees C. (149 degrees F.), is established at the