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FARMING AND GARDENING FOR HEALTH OR DISEASE

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'The civilized nations--Greece, Rome, England--have been sustained by the primitive forests which anciently rotted where they stood. They survive as long as the soil is not exhausted.'

--THOREAU, Walking and the Wild.

'The staple foods may not contain the same nutritive substances as in former times. . . . Chemical fertilizers, by increasing the abundance of the crops without replacing all the exhausted elements of the soil, have indirectly contributed to change the nutritive value of cereal grains and of vegetables. . . . Hygienists have not paid sufficient attention to the genesis of diseases. Their studies of conditions of life and diet, and of their effects on the physiological and mental state of modern man, are superficial, incomplete, and of too short duration. They have, thus, contributed to the weakening of our body and our soul.'

--ALEXIS CARREL, Man the Unknown.

The preservation of fertility is the first duty of all that live by the land. . . . There is only one rule of good husbandry--leave the land far better than you found it.'

--GEORGE HENDERSON, The Farming Ladder.

assisted by LOUISE E. HOWARD

PREFACE

The earth's green carpet is the sole source of the food consumed by livestock and mankind. It also furnishes many of the raw materials needed by our factories. The consequence of abusing one of our greatest possessions is disease. This is the punishment meted out by Mother Earth for adopting methods of agriculture which are not in accordance with Nature's law of return. We can begin to reverse this adverse verdict and transform disease into health by the proper use of the green carpet--by the faithful return to the soil of all available vegetable, animal, and human wastes.

The purpose of this book is threefold: to emphasize the importance of solar energy and the vegetable kingdom in human affairs; to record my own observations and reflections, which have accumulated during some forty-five years, on the occurrence and prevention of disease; to establish the thesis that most of this disease can be traced to an impoverished soil, which then leads to imperfectly synthesized protein in the green leaf and finally to the breakdown of those protective arrangements which Nature has designed for us.

During the course of the campaign for the reform of agriculture, now in active progress all over the world, I have not hesitated to question the soundness of present-day agricultural teaching and research--due to failure to realize that the problems of the farm and garden are biological rather than chemical. It follows, therefore, that the foundations on which the artificial manure and poison spray industries are based are also unsound. As a result of this onslaught, what has been described as the war in the soil has broken out in many countries and continues to spread. The first of the great battles now being fought began in South Africa some ten years ago and has ended in a clear-cut victory for organic farming. In New Zealand the struggle closely follows the course of the South African conflict. The contest in Great Britain and the United States of America has only now emerged from the initial phase of reconnaissance, in the course of which the manifold weaknesses of the fortress to be stormed have been discovered and laid bare.

I am indebted to some hundreds of correspondents all over the world for sending me reports of the observations, experiments, and results which have followed the faithful adoption of Nature's great law of return. Some of this information is embodied and acknowledged in the pages of this book. A great deal still remains to be summarized and reduced to order--a labour which I hope soon to begin. When it is completed, a vast mass of material will be available which will confirm and extend what is to be found in these pages. Meanwhile a portion of this evidence is being recorded by Dr. Lionel J. Picton, O.B.E., in the News-Letter on Compost issued three times a year by the County Palatine of Chester Local Medical and Panel Committees at Holmes Chapel, Cheshire. By this means the story begun in their Medical Testament of 1939 is being continued and the pioneers of organic farming and gardening are kept in touch with events.

The fourth chapter on 'The Maintenance of Soil Fertility in Great Britain' is very largely based on the labours of a friend and former colleague, the late Mr. George Clarke, C.I.E., who, a few days before his untimely death in May 1944, sent me the results of his study of the various authorities on the Saxon Conquest, the evolution of the manor, the changes it underwent as the result of the Domesday Book, and the enthronement of the Feudal System till the decay of the open-field system and its replacement by enclosure.

The spectacular progress in organic farming and gardening which has taken place in South Africa and Rhodesia during the last few years owes much to the work of Captain Moubray, Mr. J. P. J. van Vuren, and Mr. G. C. Dymond, who have very generously placed their results at my disposal. Captain Moubray and Mr. van Vuren have contributed two valuable appendices, while Mr. Dymond's pioneering work on virus disease in the cane and on composting at the Springfield Sugar Estate in Natal has been embodied in the text. For the details relating to the breakdown of the cacao industry in Trinidad and on the Gold Coast and for a number of other suggestions on African and West Indian agriculture I am indebted to Dr. H. Martin Leake, formerly Principal of the Imperial College of Tropical Agriculture, Trinidad. have been kept in constant touch with the progress of organic farming and gardening in the United States of America by Mr. J. I. Rodale of Emmaus, Pa., the editor of Organic Gardening, who has started a movement in the New World which promises soon to become an avalanche. Mr. Rodale was the prime mover in bringing out the first American edition of An Agricultural Testament and is responsible for the simultaneous publication of this present book in the United States and of a special American issue of Lady Eve Balfour's stimulating work--The Living Soil.

In India I have made full use of the experience of Colonel Sir Edward Hearle Cole, C.B., C.M.G., on the Coleyana Estate in the Punjab, and of Mr. E. F. Watson's work on the composting of water hyacinth at Barrackpore. Messrs. Walter Duncan & Company have generously permitted Mr. J. C. Watson to contribute an appendix on the remarkable results he has obtained on the Gandrapara Tea Estate in North Bengal. In this fine property India and the rest of the Empire possess a perfect example of the way Nature's law of return should be obeyed and of what freshly prepared humus by itself can achieve.

I owe much to a number of the active members of the New Zealand Compost Club, and in particular to its former Honorary Secretary, Mr. T. W. M. Ashby, who have kept me fully informed of the results obtained by this vigorous association. The nutritional results obtained by Dr. G. B. Chapman, the President, at the Mount Albert Grammar School, which show how profoundly the fresh produce of fertile soil influences the health of schoolboys, have been of the greatest use. In Eire the Rev. C. W. Sowby, Warden of the College of St. Columba, Rathfarnham, Co. Dublin, and the Rev. W. S. Airy, Head Master of St. Martin's School, Sidmouth, have placed at my disposal the results of similar work at their respective schools. These pioneering efforts are certain to be copied and to be developed far and wide. Similar ideas are now being applied to factory canteen meals in Great Britain with great success, as will be evident from what Mr. George Wood has already accomplished at the Co-operative Wholesale Society's bacon factory at Winsford in Cheshire.

For furnishing full details of a large-scale example of successful mechanized organic farming in this country and of the great possibilities of our almost unused downlands I owe much to Mr. Friend Sykes. The story of Chantry, where the results of humus without any help from artificial manures are written on the land itself, provides a fitting conclusion to this volume.

In the heavy task of getting this book into its final shape I owe much to the care and devotion of my private secretary, Miss Ellinor Kirkham.

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CHAPTER I

INTRODUCTION

AN ADVENTURE IN RESEARCH

My first post was a somewhat unusual one. It included the conventional investigation of plant diseases, but combined these duties with work on general agriculture; officially I was described as Mycologist and Agricultural Lecturer to the Imperial Department of Agriculture for the

West Indies.

The headquarters of the department were at Barbados. While I was here provided with a laboratory for investigating the fungous diseases of crops (mycology) and was given special facilities for the study of the sugar-cane, in the Windward and Leeward Islands my main work was much more general--the delivery of lectures on agricultural science to groups of schoolmasters to help them to take up nature study and to make the fullest use of school gardens.

Looking back I can now see where the emphasis of my job rightly lay. In Barbados I was a laboratory hermit, a specialist of specialists, intent on learning more and more about less and less: but in my tours of the various islands I was forced to forget my specialist studies and become interested in the growing of crops, which in these districts were principally cacao, arrowroot, ground nuts, sugar-cane, bananas, limes, oranges, and nutmegs. This contact with the land itself and with the practical men working on it laid the foundations of my knowledge of tropical agriculture.

This dual experience had not long been mine before I became aware of one disconcerting circumstance. I began to detect a fundamental weakness in the organization of that research which constituted officially the more important part of my work. I was an investigator of plant diseases, but I had myself no crops on which I could try out the remedies I advocated: I could not take my own advice before offering it to other people. It was borne in on me that there was a wide chasm between science in the laboratory and practice in the field, and I began to suspect that unless this gap could be bridged no real progress could be made in the control of plant diseases: research and practice would remain apart: mycological work threatened to degenerate into little more than a convenient agency by which--provided I issued a sufficient supply of learned reports fortified by a judicious mixture of scientific jargon--practical difficulties could be side-tracked.

Towards the end of 1902, therefore, I took steps which terminated my appointment and gave me a fresh start. My next post was more promising--that of Botanist to the South-Eastern Agricultural College at Wye in Kent, where in addition to teaching I was placed in charge of the experiments on the growing and drying of hops which had been started by the former Principal, Mr. A. D. (later Sir Daniel) Hall. These experiments brought me in contact with a number of the leading hop growers, notably Mr. Walter (afterwards Sir Walter) Berry, Mr. Alfred Amos, and Colonel Honyball--all of whom spared no pains in helping me to understand the cultivation of this most interesting crop. I began to raise new varieties of hops by hybridization and at once made a significant practical discovery--the almost magical effect of pollination in speeding up the growth and also in increasing the resistance of the developing female flowers (the hops of commerce) to green-fly and mildew (a fungous disease) which often did considerable damage. The significant thing about this work was that I was meeting the practical men on their own ground. Actually their practice--that of eliminating the male plant altogether from their hop gardens--was a wide departure from natural law. My suggestion amounted to a demand that Nature be no longer defied. It was for this reason highly successful. By restoring pollination the health, the rate of growth, and finally the yield of hops were improved. Soon the growers all over the hop-growing areas of England saw to it that their gardens were provided with male hops, which liberated ample pollen just as it was needed.

This, my first piece of really successful work, was done during the summer of 1904--five years after I began research. It was obtained by happy chance and gave me a glimpse of the way Nature regulates her kingdom: it also did much to strengthen my conviction that the most promising method of dealing with plant diseases lay in prevention--by tuning up agricultural practice. But to continue such work the investigator would need land and hops of his own with complete freedom to grow them in his own way. Such facilities were not available and did not seem possible at Wye.

Then my chance came. Early in 1905 I was offered and accepted the post of Economic Botanist at the Agricultural Research Institute about to be founded by Lord Curzon, the then Viceroy of India, at Pusa in Bengal. On arrival in India in May 1905 the new institute only existed on paper, but an area of about seventy-five acres of land at one end of the Pusa Estate had not yet been allocated. I secured it instantly and spent my first five years in India learning how to grow the crops which it was my duty to improve by modern plant-breeding methods.

It was a decided advantage that officially my work was now no longer concerned merely with the narrow problem of disease My main duties at Pusa were the improvement of crops and the production of new varieties. Over a period of nineteen years (1905-24) my time was devoted to this task, in the course of which many new types of wheat (including rust-resistant varieties), of tobacco, gram, and linseed were isolated, tested, and widely distributed.

In pursuance of the principle I had adopted of joining practice to my theory, the first step was to grow the crops I had to improve. I determined to do so in close conformity with local methods. Indian agriculture can point to a history of many centuries: there are records of the same rice fields being farmed in north-east India which go back for hundreds of years. What could be more sensible than to watch and learn from an experience which had passed so prolonged a test of time? I therefore set myself to make a preliminary study of Indian agriculture and speedily found my reward.

Now the crops grown by the cultivators in the neighbourhood of Pusa were remarkably free from pests: such things as insecticides and fungicides found no place in this ancient system of cultivation. This was a very striking fact, and I decided to break new ground and try out an idea which had first occurred to me in the West Indies and had forced itself on my attention at Wye, namely, to observe what happened when insect and fungous diseases were left alone and allowed to develop unchecked, indirect methods only, such as improved cultivation and more efficient varieties, being employed to prevent attacks.

In pursuit of this idea I found I could do no better than watch the operations of the peasants as aforesaid and regard them and the pests for the time being as my best instructors.

In order to give my crops every chance of being attacked by parasites nothing was done in the way of direct prevention; no insecticides and fungicides were used; no diseased material was ever destroyed. As my understanding of Indian agriculture progressed and as my practice improved, a marked diminution of disease in my crops occurred. At the end of five years' tuition under my new professors--the peasants and the pests--the attacks of insects and fungi on all crops whose root systems suited the local soil conditions became negligible. By 1910 I had learnt how to grow healthy crops, practically free from disease, without the slightest help from mycologists, entomologists, bacteriologists, agricultural chemists, statisticians, clearing-houses of information, artificial manures, spraying machines, insecticides, fungicides, germicides, and all the other expensive paraphernalia of the modern experiment station.

This preliminary exploration of the ground suggested that the birthright of every crop is health.

In the course of the cultivation of the seventy-five acres at my disposal I had to make use of the ordinary power unit in Indian agriculture, which is oxen. It occurred to me that the same practices which had been so successful in the growing of my crops might be worth while if applied to my animals. To carry out such an idea it was necessary to have these work cattle under my own charge, to design their accommodation, and to arrange for their feeding, hygiene, and management. At first this was refused, but after persistent importunity backed by the powerful support of the Member of the Viceroy's Council in charge of Agriculture (the late Sir Robert Carlyle, K.C.S.I.), I was allowed to have charge of six pairs of oxen. I had little to learn in this matter, as I belong to an old agricultural family and was brought up on a farm which had made for itself a local reputation in the management of cattle. My work animals were most carefully selected and everything was done to provide them with suitable housing and with fresh green fodder, silage, and grain, all produced from fertile land. I was naturally intensely interested in watching the reaction of these well-chosen and well-fed oxen to diseases like rinderpest, septicaemia, and foot-and-mouth disease which frequently devastated the countryside. (These epidemics are the result of starvation, due to the intense pressure of the bovine population on the limited food supply.) None of my animals were segregated; none were inoculated; they frequently came in contact with diseased stock. As my small farmyard at Pusa was only separated by a low hedge from one of the large cattle-sheds on the Pusa estate, in which outbreaks of foot-and-mouth disease often occurred, I have several times seen my oxen rubbing noses with foot-and-mouth cases. Nothing happened. The healthy, well-fed animals failed to react to this disease exactly as suitable varieties of crops, when properly grown, did to insect and fungous pests--no infection took place. These experiences were afterwards repeated at Indore in Central India, but here I had forty not twelve oxen. A more detailed account of the prevention and cure of foot-and-mouth disease is given in a later chapter (p. 153).

These observations, important as they appeared both at the time and in retrospect, were however only incidental to my main work which was, as already stated, the improvement of the varieties of Indian crops, especially wheat. It was in the testing of the new kinds, which in the case of wheat soon began to spread over some millions of acres of India, that there gradually emerged the principle of which my observations about disease did but supply the first links in evidence: namely, that the foundations of all good cultivation lie not so much in the plant as in the soil itself: there is so intimate a connection between the state of the soil, i.e. its fertility, and the growth and health of the plant as to outweigh every other factor. Thus on the capital point of increase of yield, if by improvement in selection and breeding my new special varieties of wheat, etc., might be estimated to produce an increase of 10 to 15 per cent, such yields could at once be increased not by this paltry margin, but doubled or even trebled, when the new variety was grown in soil brought up to the highest state of fertility. My results were afterwards amply confirmed by my colleague, the late Mr. George Clarke, C.I.E., who, by building up the humus content of his experiment station at Shahjahanpur in the United Provinces and by adopting simple improvements in cultivation and green-manuring, was able to treble the yields of sugar-cane and wheat.

Between the years 1911 and 1918 my experience was considerably enlarged by the study of the problems underlying irrigation and fruit growing. For this purpose I was provided with a small experimental farm on the loess soils of the Quetta valley in Baluchistan where, till 1918, the summer months were spent. After a supply of moisture had been provided to supplement the scanty winter rainfall, the limiting factors in crop production proved to be soil aeration and the humus content of the land. Failure to maintain aeration was indicated by a disease of the soil itself. The soil flora became anaerobic: alkali salts developed: the land died. The tribesmen kept the alkali condition at bay in their fruit orchards in a very suggestive manner--by means of the deep-rooting system of lucerne combined with surface dressings of farmyard manure.

Moreover they invariably combined their fruit growing with mixed farming and livestock. Nowhere, as in the West, did one find the whole farm devoted to fruit with no provision for an adequate supply of animal manure. This method of fruit growing was accompanied by an absence of insect and fungoid diseases: spraying machines and poison sprays were unheard of: artificial manures were never used. The local methods of grape growing were also intensely interesting. To save the precious irrigation water and as a protection from the hot, dry winds, the vines were planted in narrow ditches dug on the slopes of the valley and were always manured with farmyard manure. Irrigation water was led along the ditches and the vines were supported by the steep sides of the trenches. At first sight all the conditions for insect and fungous diseases seemed to be provided, but the plants were remarkably healthy. I never found even a trace of disease. The quality of the produce was excellent: the varieties grown were those which had been in cultivation in Afghanistan for centuries. No signs of running out were observed. Here were results in disease resistance and in the stability of the variety in striking contrast to those of western Europe, where disease is notorious, the use of artificial manures and poison sprays is universal, and where the running out of the variety is constantly taking place (see also p. 135).

These results and observations taken together and prolonged over a period of nineteen years at length indicated what should be the right method of approach to the work I was doing. Improvement of varieties, increased yields, freedom from disease were not distinct problems, but formed parts of one subject and, so to speak, were members one of another, all arising out of the great linkage between the soil, the plant, and the animal. The line of advance lay not in dealing with these factors separately but together. If this were to be the path of progress and if it was useless to proceed except on the basis of crops grown on fertile land, then the first prerequisite for all subsequent work would be just the bringing of the experiment station area to the highest state of fertility and maintaining it in that condition.

This, however, opened up a further problem. The only manure at the command of the Indian cultivator was farmyard manure. Farmyard manure was therefore essential, but even on the experiment stations the supply of this material was always insufficient. The problem was how to increase it in a country where a good deal of the cattle-dung has to be burnt for fuel. No lasting good could be achieved unless this problem were overcome, for no results could be applied to the country at large.

The solution was suggested by the age-long practices of China, where a system of utilizing farm wastes and turning them into humus had been evolved which, if applied to India, would make every Indian holding self-supporting as regards manure. This idea called for investigation.

I now came up against a very great difficulty. Such a problem did not fall within my official sphere of work. It obviously necessitated a great deal of chemical and agricultural investigation under my personal control and complete freedom to study all aspects of the question. But while my idea was taking shape, the organization of agricultural research at Pusa had also developed. A series of watertight compartments--plant breeding, mycology, entomology, bacteriology, agricultural chemistry, and practical agriculture--had become firmly established. Vested interests were created which regarded the organization as more important than its purpose. There was no room in it for a comprehensive study of soil fertility and its many implications by one member of the staff with complete freedom of action. My proposals involved 'overlapping', a defect which was anathema both to the official mind (which controlled finance) and to a research institute subdivided as Pusa always had been.

The obvious course was to leave the institute and to collect the funds to found a new centre where I could follow the gleam unhampered and undisturbed. After a delay of six precious years, 1918-24, the Indore Institute of Plant Industry (at which cotton was the principal crop) was founded, where I was provided with land, ample money, and complete freedom. Now the fundamental factor underlying the problems of Indian cotton was none other than the raising of soil fertility. I might therefore kill two birds with one stone. I could solve the cotton problem if I could increase the amount of farmyard manure for India as a whole.

At Indore I had a considerably larger area at my disposal, namely, 300 acres. From the outset the principles which I had worked out at Pusa were applied to cotton. The results were even better. The yield of cotton was almost trebled and the whole experiment station area stood out from the surrounding countryside by reason of the fine crops grown. Moreover these crops were free from disease, with only two exceptions, during the whole eight years of my work there, exceptions in themselves highly significant. A small field of gram, which had become accidentally waterlogged three months before the crop was sown, was, a month after sowing, found to be heavily attacked by the gram caterpillar, the infected areas corresponding with the waterlogged areas with great exactness, while the rest of the plot remained unaffected: the caterpillar did not spread, though nothing was done to check it. In the second case a field of san hemp (Crotalaria juncea, L.), originally intended for green-manuring, was allowed to flower for seed; after flowering it was smothered in mildew and insect pests and no seed set. Subsequent trials showed that this crop will set seed and be disease free on black soils only if the land is previously well manured with farmyard manure or compost.

These results were progressive confirmation of the principle I was working out--the connection between land in good heart and disease-free crops: they were proof that as soon as land drops below par, disease may set in. The first case showed the supreme importance of keeping the physical texture of the soil right, the second was an interesting example of the refusal of Mother Earth to be overworked, of her unbreakable rule to limit herself strictly to that volume of operations for which she has sufficient reserves: flowers were formed, but seed refused to set and the mildew and insects were called in to remove the imperfect product.

These were the exceptions to prove the rule, for during the eight years of my work at Indore it was assumed by me as a preliminary condition to all experiments that my fields must be fertile. This was brought about by supplying them with heavy dressings of compost made on a simple development of the Chinese system. As I was now free, it was possible for me to make these arrangements on a large scale, and in the course of doing so it seemed well worth while to work out the theory that underlay the empiric Chinese practice. A complete series of experiments and investigations were carried out, establishing the main chemical, physical, and biological processes which go to humus formation in the making of compost. In this work I received valuable help from Mr. Y. D. Wad who was in charge of the chemical side of the investigation. On my retirement from official service in 1931 I assumed that the publication of this joint work in book form would be the last scientific task which I should ever undertake.

It proved instead to be the beginning of a new period which has been based on the long preparation which preceded it: the years of work and experiment carried out in the tropics had gradually but inevitably led me up to the threshold of ideas which embrace and explain the facts and the practices, the theory and also the failures, which had met me in the course of these thirty-two years. Our book on The Waste Products of Agriculture; Their Utilization as Humus, designed to be a practical guide to assist the Indian cotton cultivators, evoked a much wider interest. The so-called Indore Process of making compost was started at a number of centres in other countries and interesting results began to be reported, very much like what I had obtained at Indore.

Two years after publication, in February 1933, I saw the inception of a compost-making scheme at Colonel Grogan's estate not far from Nairobi in Kenya Colony. During this visit it first occurred to me gradually to terminate all my other activities and to confine myself to encouraging the pioneers engaged in agriculture all over the world to restore and maintain the fertility of their land. This would involve a campaign to be carried out single-handed at my own expense as no official funds could be expected for a project such as mine. Even if I could have obtained the means needed it would have been necessary to work with research organizations I had long regarded not only as obsolete, but as the perfect means of preventing progress. A soil fertility campaign carried on by a retired official would also throw light on another question, namely, the relative value of complete freedom and independence in getting things done in farming, as compared with the present cumbrous and expensive governmental organization.

By the end of 1933 matters had progressed far enough to introduce the Indore Process to a wider public. This was done by means of two lectures before the Royal Society of Arts in 1933 and 1935, some thousands of extra copies of both of which were distributed all over the world, and subsequent contributions to the Journal of that society, to a German periodical--Der Tropenflanzer--and a Spanish review--the Revista del Instituto de Defensa del Cafe of Costa Rica. The process became generally known and was found to be a most advantageous proposition in the big plantation industries--coffee, tea, sugar, maize, tobacco, sisal, rice, and vine--yields and quality alike being notably improved. I devoted my energies to advising and assisting those interested, and during this period became greatly indebted to the tea industry for material help and encouragement.

In 1937 results were reported in the case of tea which were difficult to explain. Single light dressings of Indore compost improved the yield of leaf and increased the resistance of the bush to insect attacks in a way which much surpassed what was normally to be expected from a first application. While considering these cases I happened to read an account of Dr. Rayner's work on conifers at Wareham in Dorsetshire, where small applications of humus had also produced spectacular results. Normally humus is considered to act on the plant indirectly: the oxidation of the substances composing it ultimately forming salts in the soil, which are then absorbed by the root hairs in the usual processes of nutrition. Was there here, however, something more than this, some direct action having an immediate effect and one very powerful?

Such indeed has proved to be the case and the explanation can now be set forth of the wonderful double process by which Nature causes the plant to draw its nurture from the soil. The mechanism by which living fungous threads (mycelium) invade the cells of the young roots and are gradually digested by these is described in detail in a later chapter (p. 28). It was this, the mycorrhizal association, which was the explanation of what had happened to the conifers and the tea shrubs, both forest plants, a form of vegetation in which this association of root and fungus has been known for a long time. This direct method of feeding would account for the results observed (p. 33).

A number of inquiries which I was now able to set on foot revealed the existence of this natural feeding mechanism in plant after plant, where it had hitherto neither been observed nor looked for, but only, be it noted, where there was ample humus in the soil. Where humus was wanting, the mechanism was either absent or ineffective: the plant was limited to the nurture derived by absorption of the salts in the soil solution: it could not draw on these rich living threads, abounding in protein.

The importance of the opening up of this aspect of plant nutrition was quite obvious. Here at last was a full and sufficient explanation of the facts governing the health of plants. From this point on evidence began to accumulate to illumine the new path of inquiry, which in my opinion is destined to lead us a very long way indeed. It was clear that the doubling of the processes of plant nutrition was one of those reserve devices on which rests the permanence and stability of Nature. Plants deprived of the mycorrhizal association continue to exist, but they lose both their power to resist shock and their capacity to reproduce themselves. A new set of facts suddenly fell into place: the running out of varieties, a marked phenomenon of modern agriculture, to answer which new varieties of the important crops have constantly to be bred--hence the modern plant breeding station--could without hesitation be attributed to the continued impoverishment of modern soils owing to the prolonged negligence of the Western farmer to feed his fields with humus. By contrast the maintenance of century-old varieties in the East, so old that in India they bear ancient Sanskrit names, was proof of the unimpaired capacity of the plant to breed in those countries where humus was abundantly supplied.

The mycorrhizal association may not prove to be the only path by which the nitrogen complexes derived from the digestion of proteins reach the sap. Humus also nourishes countless millions of bacteria whose dead bodies leave specks of protein thickly strewn throughout the soil. But these complex bodies are not permanent: they are reduced by other soil organisms to simpler and simpler bodies which finally become mineralized to form the salts taken up by the roots for use in the green leaves. May not some of the very early stages in the oxidation of these specks of protein be absorbed by the root hairs from the soil water? It would seem so, because a few crops exist, like the tomato, which although reacting to humus are not provided with the mycorrhizal association. This matter is discussed in the next chapter (p. 28).

These results set up a whole train of thought. The problem of disease and health took on a wider scope. In March 1939 new ground was broken. The Local Medical and Panel Committees of Cheshire, summing up their experience of the working of the National Health Insurance Act for over a quarter of a century in the county, did not hesitate to link up their judgment on the unsatisfactory state of health of the human population under their care with the problem of nutrition, tracing the line of fault right back to an impoverished soil and supporting their contentions by reference to the ideas which I had for some time been advocating. Their arguments were powerfully supported by the results obtained at the Peckham Health Centre and by the work, already published, of Sir Robert McCarrison, which latter told the story from the other side of the world and from a precisely opposite angle--he was able to instance an Eastern people, the Hunzas, who were the direct embodiment of an ideal of health and whose food was derived from soil kept in a state of the highest natural fertility.

By these contemporaneous pioneering efforts the way was blazed for treating the whole problem of health in soil, plant, animal, and man as one great subject, calling for a boldly revised point of view and entirely fresh investigations.

By this time sufficient evidence had accumulated for setting out the case for soil fertility in book form. This was published in June 1940 by the Oxford University Press under the title of An Agricultural Testament. This book, now in its fourth English and second American edition, set forth the whole gamut of connected problems as far as can at present be done--what wider revelations the future holds is not yet fully disclosed. In it I summed up my life's work and advanced the following views:

1. The birthright of all living things is health.

2. This law is true for soil, plant, animal, and man: the health of these four is one connected chain.

3. Any weakness or defect in the health of any earlier link in the chain is carried on to the next and succeeding links, until it reaches the last, namely, man.

4. The widespread vegetable and animal pests and diseases, which are such a bane to modern agriculture, are evidence of a great failure of health in the second (plant) and third (animal) links of the chain.

5. The impaired health of human populations (the fourth link) in modern civilized countries is a consequence of this failure in the second and third links.

6. This general failure in the last three links is to be attributed to failure in the first link, the soil: the undernourishment of the soil is at the root of all. The failure to maintain a healthy agriculture has largely cancelled out all the advantages we have gained from our improvements in hygiene, in housing, and our medical discoveries.

7. To retrace our steps is not really difficult if once we set our minds to the problem. We have to bear in mind Nature's dictates, and we must conform to her imperious demand: (e) for the return of all wastes to the land; (b) for the mixture of the animal and vegetable existence; (c) for the maintaining of an adequate reserve system of feeding the plant, i.e. we must not interrupt the mycorrhizal association. If we are willing so far to conform to natural law, we shall rapidly reap our reward not only in a flourishing agriculture, but in the immense asset of an abounding health in ourselves and in our children's children.

These ideas, straightforward as they appear when set forth in the form given above, conflict with a number of vested interests. It has been my self-appointed task during the last few years of my life to join hands with those who are convinced of their truth to fight the forces impeding progress. So large has been the flow of evidence accumulating that in 1941 it was decided to publish a News-Letter on Compost, embodying the most interesting of the facts and opinions reaching me or others in the campaign. The News-Letter, which appears three times a year under the aegis of the Cheshire Local Medical and Panel Committees, has grown from eight to sixty-four pages and is daily gaining new readers.

The general thesis that no one generation has a right to exhaust the soil from which humanity must draw its sustenance has received further powerful support from religious bodies. The clearest short exposition of this idea is contained in one of the five fundamental principles adopted by the recent Malvern Conference of the Christian Churches held with the support of the late Archbishop of Canterbury, Dr. Temple. It is as follows: 'The resources of the earth should be used as God's gifts to the whole human race and used with due consideration for the needs of the present and future generations.'

Food is the chief necessity of life. The plans for social security which are now being discussed merely guarantee to the population a share in a variable and, in present circumstances, an uncertain quantity of food, most of it of very doubtful quality. Real security against want and ill health can only be assured by an abundant supply of fresh food properly grown in soil in good heart. The first place in post-war plans of reconstruction must be given to soil fertility in every part of the world. The land of this country and the Colonial Empire, which is the direct responsibility of Parliament, must be raised to a higher level of productivity by a rational system of farming which puts a stop to the exploitation of land for the purpose of profit and takes into account the importance of humus in producing food of good quality. The electorate alone has the power of enforcing this and to do so it must first realize the full implications of the problem.

They and they alone possess the power to insist that every boy and every girl shall enter into their birthright--health, and that efficiency, well-being, and contentment which depend thereon. One of the objects of this book is to show the man in the street how this England of ours can be born again. He can help in this task, which depends at least as much on the plain efforts of the plain man in his own farm, garden, or allotment as on all the expensive paraphernalia, apparatus, and elaboration of the modern scientist: more so in all probability, inasmuch as one small example always outweighs a ton of theory. If this sort of effort can be made and the main outline of the problems at stake are grasped, nothing can stop an immense advance in the well-being of this island. A healthy population will be no mean achievement, for our greatest possession is ourselves.

The man in the street will have to do three things:

1. He must create in his own farm, garden, or allotment examples without end of what a fertile soil can do.

2. He must insist that the public meals in which he is directly interested, such as those served in boarding schools, in the canteens of day schools and of factories, in popular restaurants and tea shops, and at the seaside resorts at which he takes his holidays are composed of the fresh produce of fertile soil.

3. He must use his vote to compel his various representatives--municipal, county, and parliamentary--to see to it: (a) that the soil of this island is made fertile and maintained in this condition; (b) that the public health system of the future is based on the fresh produce of land in good heart.

This introduction started with the training of an agricultural investigator: it ends with the principles underlying the public health system of to-morrow. It has, therefore, covered much ground in describing what is nothing less than an adventure in scientific research. One lesson must be stressed. The difficulties met with and overcome in the official portion of this journey were not part of the subject investigated. They were man made and created by the research organization itself. More time and energy had to be expended in side-tracking the lets and hindrances freely strewn along the road by the various well-meaning agencies Which controlled discovery than in conducting the investigations themselves. When the day of retirement came, all these obstacles vanished and the delights of complete freedom were enjoyed. Progress was instantly accelerated. Results were soon obtained throughout the length and breadth of the English-speaking world, which make crystal clear the great role which soil fertility must play in the future of mankind.

The real Arsenal of Democracy is a fertile soil, the fresh produce of which is the birthright of the nations.

PART I THE PART PLAYED BY SOIL FERTILITY IN AGRICULTURE

CHAPTER II

THE OPERATIONS OF NATURE

The introduction to this book describes an adventure in agricultural research and records the conclusions reached. If the somewhat unorthodox views set out are sound, they will not stand alone but will be supported and confirmed in a number of directions--by the farming experience of the past and above all by the way Nature, the supreme farmer, manages her kingdom. In this chapter the manner in which she conducts her various agricultural operations will be briefly reviewed. In surveying the significant characteristics of the life--vegetable and animal--met with in Nature particular attention will be paid to the importance of fertility in the soil and to the occurrence and elimination of disease in plants and animals.

What is the character of life on this planet? What are its great qualities? The answer is simple. The outstanding characteristics of Nature are variety and stability.

The variety of the natural life around us is such as to strike even the child's imagination, who sees in the fields and copses near his home, in the ponds and streams and seaside pools round which he plays, or, if being city-born he be deprived of these delightful playgrounds, even in his poor back-garden or in the neighbouring park, an infinite choice of different flowers and plants and trees, coupled with an animal world full of rich changes and surprises, in fact, a plenitude of the forms of living things constituting the first and probably the most powerful introduction he will ever receive into the nature of the universe of which he is himself a part.

The infinite variety of forms visible to the naked eye is carried much farther by the microscope. When, for example, the green slime in stagnant water is examined, a new world is disclosed--a multitude of simple flowerless plants--the blue-green and the green algae--always accompanied by the lower forms of animal life. We shall see in a later chapter (p. 126) that on the operations of these green algae the well-being of the rice crop, which nourishes countless millions of the human race, depends. If a fragment of mouldy bread is suitably magnified, members of still another group of flowerless plants, made up of fine, transparent threads entirely devoid of green colouring matter, come into view. These belong to the fungi, a large section of the vegetable kingdom, which are of supreme importance in farming and gardening.

It needs a more refined perception to recognize throughout this stupendous wealth of varying shapes and forms the principle of stability. Yet this principle dominates. It dominates by means of an ever-recurring cycle, a cycle which, repeating itself silently and ceaselessly, ensures the continuation of living matter. This cycle is constituted of the successive and repeated processes of birth, growth, maturity, death, and decay.

An eastern religion calls this cycle the Wheel of Life and no better name could be given to it. The revolutions of this Wheel never falter and are perfect. Death supersedes life and life rises again from what is dead and decayed.

Because we are ourselves alive we are much more conscious of the processes of growth than we are of the processes involved in death and decay. This is perfectly natural and justifiable. Indeed, it is a very powerful instinct in us and a healthy one. Yet, if we are fully grown human beings, our education should have developed in our minds so much of knowledge and reflection as to enable us to grasp intelligently the vast role played in the universe by the processes making up the other or more hidden half of the Wheel. In this respect, however, our general education in the past has been gravely defective partly because science itself has so sadly misled us. Those branches of knowledge dealing with the vegetable and animal kingdoms--botany and zoology--have confined themselves almost entirely to a study of living things and have given little or no attention to what happens to these units of the universe when they die and to the way in which their waste products and remains affect the general environment on which both the plant and animal world depend. When science itself is unbalanced, how can we blame education for omitting in her teaching one of the things that really matter

For though the phases which are preparatory to life are, as a rule, less obvious than the phases associated with the moment of birth and the periods of growth, they are not less important. If once we can grasp this and think in terms of ever-repeated advance and recession, recession and advance, we have a truer view of the universe than if we define death merely as an ending of what has been alive.

Nature herself is never satisfied except by an even balancing of her processes--growth and decay. It is precisely this even balancing which gives her unchallengeable stability. That stability is rock-like. Indeed, this figure of speech is a poor one, for the stability of Nature is far more permanent than anything we can call a rock--rocks being creations which themselves are subject to the great stream of dissolution and rebirth, seeing that they suffer from weathering and are formed again, that they can be changed into other substances and caught up in the grand process of living: they too, as we shall see (p. 88), are part of the Wheel of Life. However, we may at a first glance omit the changes which affect the inert masses of this planet, petrological and mineralogical: though very soon we shall realize how intimate is the connection even between these and what is, in the common parlance, alive. There is a direct bridge between things inorganic and things organic and this too is part of the Wheel.

But before we start on our examination of that part of the great process which now concerns us--namely, plant and animal life and the use man makes of them--there is one further idea which we must master. It is this. The stability of Nature is secured not only by means of a very even balancing of her Wheel, by a perfect timing, so to say, of her mechanisms, but also rests on a basis of enormous reserves. Nature is never a hand-to-mouth practitioner. She is often called lavish and wasteful, and at first sight one can be bewildered and astonished at the apparent waste and extravagance which accompany the carrying on of vegetable and animal existence. Yet a more exact examination shows her working with an assured background of accumulated reserves, which are stupendous and also essential. The least depletion in these reserves induces vast changes and not until she has built them up again does she resume the particular process on which she was engaged. A realization of this principle of reserves is thus a further necessary item in a wide view of natural law. Anyone who has recovered from a serious illness, during which the human body lives partly on its own reserves, will realize how Nature afterwards deals with such situations. During the period of convalescence the patient appears to make little progress till suddenly he resumes his old-time activities. During this waiting period the reserves used up during illness are being replenished.

THE LIFE OF THE PLANT

A survey of the Wheel of Nature will best start from that rather rapid series of processes which cause what we commonly call living matter to come into active existence; that is, in fact, from the point where life most obviously, to our eyes, begins. The section of the Wheel embracing these processes is studied in physiology from the Greek, meaning to bring to life, to grow.

But how does life begin on this planet? We can only say this: that the prime agency in carrying it on is sunlight, because it is the source of energy, and that the instrument for intercepting this energy and turning it to account is the green leaf.

This wonderful little example of Nature's invention is a battery of intricate mechanisms. Each cell in the interior of a green leaf contains minute specks of a substance called chlorophyll and it is this chlorophyll which enables the plant to grow. Growth implies a continuous supply of nourishment. Now plants do not merely collect their food: they manufacture it before they can feed. In this they differ from animals and man, who search for what they can pass through their stomachs and alimentary systems, but cannot do more; if they are unable to find what is suitable to their natures and ready for them, they perish. A plant is, in a way, a more wonderful instrument. It is an actual food factory, making what it requires before it begins the processes of feeding and digestion. The chlorophyll in the green leaf, with its capacity for intercepting the energy of the sun, is the power unit that, so to say, runs the machine. The green leaf enables the plant to draw simple raw materials from diverse sources and to work them up into complex combinations.

Thus from the air it absorbs carbon-dioxide (a compound of two parts of oxygen to one of carbon), which is combined with more oxygen from the atmosphere and with other substances, both living and inert, drawn from the soil and from the water which permeates the soil. All these raw materials are then assimilated in the plant and made into food. They become organic compounds, i.e. compounds of carbon, classified conveniently into groups known as carbohydrates, proteins, and fats; together with an enormous volume of water (often over 90 per cent of the whole plant) and interspersed with small quantities of chemical salts which have not yet been converted into the organic phase, they make up the whole structure of the plant--root, stem, leaf, flower, and seed. This structure includes a big food reserve. The life principle, the nature of which evades us and in all probability always will, resides in the proteins looked at in the mass. These proteins carry on their work in a cellulose framework made up of cells protected by an outer integument and supported by a set of structures known as the vascular bundles, which also conduct the sap from the roots to the leaves and distribute the food manufactured there to the various centres of growth. The whole of the plant structures are kept turgid by means of water.

The green leaf, with its chlorophyll battery, is therefore a perfectly adapted agency for continuing life. It is, speaking plainly, the only agency that can do this and is unique. Its efficiency is of supreme importance. Because animals, including man, feed eventually on green vegetation, either directly or through the bodies of other animals, it is our sole final source of nutriment. There is no alternative supply. Without sunlight and the capacity of the earth's green carpet to intercept its energy for us, our industries, our trade, and our possessions would soon be useless. It follows therefore that everything on this planet must depend on the way mankind makes use of this green carpet, in other words on its efficiency.

The green leaf does not, however, work by itself. It is only a part of the plant. It is curious how easy it is to forget that normally we see only one-half of each flowering plant, shrub, or tree: the rest is buried in the ground. Yet the dying down of the visible growth of many plants in the winter, their quick reappearance in the spring, should teach us how essential and important a portion of all vegetation lives out of our sight; it is evident that the root system, buried in the ground, also holds the life of the plant in its grasp. It is therefore not surprising to find that leaves and roots work together, forming a partnership which must be put into fresh working order each season if the plant is to live and grow, If the function of the green leaf armed with its chlorophyll is to manufacture the food the plant needs, the purpose of the roots is to obtain the water and most of the raw materials required--the sap of the plant being the medium by which these raw materials (collected from the soil by the roots) are moved to the leaf. The work of the leaf we found to be intricate: that of the roots is not less so. What is surprising is to come upon two quite distinct ways in which the roots set about collecting the materials which it is their business to supply to the leaf; these two methods are carried on simultaneously. We can make a very shrewd guess at the master principle which has put the second method alongside the first: it is again the principle of providing a reserve--this time of the vital proteins.

None of the materials that reach the green leaf by whatever method is food: it is only the raw stuff from which food can be manufactured. By the first method, which is the most obvious one, the root hairs search out and pass into the transpiration current of the plant dissolved substances which they find in the thin films of water spread between and around each particle of earth; this film is known as the soil solution. The substances dissolved in it include gases (mainly carbon dioxide and oxygen) and a series of other substances known as chemical salts like nitrates, compounds of potassium and phosphorus, and so forth, all obtained by the breaking down of organic matter or from the destruction of the mineral portions of the soil. In this breaking down of organic matter we see in operation the reverse of the building-up process which takes place in the leaf. Organic matter is continuously reverting to the inorganic state: it becomes mineralized: nitrates are one form of the outcome. It is the business of the root hairs to absorb these substances from the soil solution and to pass them into the sap, so that the new life-building process can start up again. In a soil in good heart the soil solution will be well supplied with these salts. Incidentally we may note that it has been the proved existence of these mineral chemical constituents in the soil which, since the time of Liebig, has focused attention on soil chemistry and has emphasized the passage of chemical food materials from soil to plant to the neglect of other considerations.

But the earth's green carpet is not confined to its remarkable power of transforming the inert nitrates and mineral contents of the soil into an active organic phase: it is utilized by Nature to establish for itself, in addition, a direct connection, a kind of living bridge, between its own life and the living portion of the soil. This is the second method by which plants feed themselves. The importance of this process, physiological in nature and not merely chemical, cannot be over-emphasized and some description of it will now be attempted.

THE LIVING SOIL

The soil is, as a matter of fact, full of live organisms. It is essential to conceive of it as something pulsating with life, not as a dead or inert mass. There could be no greater misconception than to regard the earth as dead: a handful of soil is teeming with life. The living fungi, bacteria, and protozoa, invisibly present in the soil complex, are known as the soil population. This population of millions and millions of minute existences, quite invisible to our eyes of course, pursue their own lives. They come into being, grow, work, and die: they sometimes fight each other, win victories, or perish; for they are divided into groups and families fitted to exist under all sorts of conditions. The state of a soil will change with the victories won or the losses sustained, and in one or other soil, or at one or other moment, different groups will predominate.

This lively and exciting life of the soil is the first thing that sets in motion the great Wheel of Life. Not without truth have poets and priests paid worship to 'Mother Earth', the source of our being. What poetry or religion have vaguely celebrated, science has minutely examined, and very complete descriptions now exist of the character and nature of the soil population, the various species of which have been classified, labelled, and carefully observed. It is this life which is continually being passed into the plant.

The process can actually be followed under the microscope. Some of the individuals belonging to one of the most important groups in this mixed population--the soil fungi--can be seen functioning. If we arrange a vertical darkened glass window on the side of a deep pit in an orchard, it is not difficult to see with the help of a good lens or a low-power horizontal microscope (arranged to travel up and down a vertical fixed rod) some of these soil fungi at work. They are visible in the interstices of the soil as glistening white branching threads, reminiscent of cobwebs. In Dr. Rogers's interesting experiments on the root systems of fruit trees at East Malling Research Station, where this method of observing them was initiated and demonstrated to me, these fungous threads could be seen approaching the young apple roots in the absorbing region (just behind the advancing root tips) on which the root hairs are to be found. Dr. Rogers very kindly presented me with two excellent photographs--one showing the general arrangement of his observation chamber (Plate I), the other, taken on 6th July 1933, of a root tip (magnified by about twelve) of Lane's Prince Albert (grafted on root stock XVI) at sixteen inches below the surface, showing abundant fungous strands running in the soil and coming into direct contact with the growing root (Plate II).

PLATE I. OBSERVATION CHAMBER FOR ROOT STUDIES AT EAST MALLING

But this is only the beginning of the story. When a suitable section of one of these young apple roots, growing in fertile soil and bearing active root hairs, is examined, it will be found that these fine fungous threads actually invade the cells of the root, where they can easily be observed passing from one cell to another. But they do not remain there very long. After a time the apple roots absorb these threads. All stages of the actual digestion can be seen.

The significance of this process needs no argument. Here we have a simple arrangement on the part of Nature by which the soil material on which these fungi feed can be joined up, as it were, with the sap of the tree. These fungous threads are very rich in protein and may contain as much as 10 per cent of organic nitrogen; this protein is easily digested by the ferments (enzymes) in the cells of the root; the resulting nitrogen complexes, which are readily soluble, are then passed into the sap current and so into the green leaf. An easy passage, as it were, has been provided for food material to move from soil to plant in the form of proteins and their digestion products, which latter in due course reach the green leaf. The marriage of a fertile soil and the tree it nourishes is thus arranged. Science calls these fungous threads mycelium (again from a Greek word, xxxxx), and as the Greek for root is xxx (rhiza, cf. rhizome), the whole process is known as the mycorrhizal association.

The reader who wishes to delve into the technical details relating to the mycorrhizal association and its bearing on forestry and agriculture should consult the following works:--

1. Rayner, M. C. and Neilson-Jones, W.--Problems in Tree Nutrition, Faber & Faber, London, 1944.

2. Balfour, Lady Eve--The Living Soil, Faber & Faber, London, 1944.

3. Howard, Sir Albert--An Agricultural Testament, Oxford Press, 1940.

What is urgently needed at the moment is an account in simple, non-technical language, of this remarkable link between a fertile soil and the roots of the vast majority of flowering plants and its significance in nutrition and disease resistance.

PLATE II. THE BEGINNINGS OF MYCORRHIZAL ASSOCIATION IN THE APPLE
Root-tip (x 12) of Lane's Prince Albert on root-stock M XVI at sixteen inches below the surface, showing root-cap (A), young root hairs (C), and older root hairs with drops of exudate (Cl). The cobweb-like mycelial strands are well seen approaching the rootlet in the region marked (C).

This partnership is universal in the forest and is general throughout the vegetable kingdom. A few exceptions, however, exist which will be referred to in the next paragraph.

Among the plants in which this mycorrhizal association has hitherto not been observed are the tomato and certain cultivated members of the cabbage family, many of which possess a very diffuse root system and exceptionally elongated root hairs. Nevertheless, all these examples respond very markedly to the condition of the soil in which they are grown and if fed with dressings of humus will prosper. The question naturally arises: Exactly how does this take place? What is the alternative mechanism that replaces the absent mycorrhizal association?

A simple explanation would appear to be this. Fertile soils invariably contain a greatly enhanced bacterial population whose dead remains must be profusely scattered in the water films which bathe the compound soil particles and the root hairs of the crops themselves; these specks of dead organic matter, rich in protein, are finally mineralized into simple salts like nitrates. We have already mentioned this breaking-down process of the soil population. What is here to be noted is that it is no sudden transformation, but takes place in stages. May not, therefore, some at least of the first-formed nitrogen complexes, which result from this breaking down, be absorbed by the root hairs and so added to the sap current? That is to say that the non-mycorrhiza-forming plants, not drawing on the soil fungi, do compensate themselves by absorbing organic nitrogen in this form--they catch the bacterial soil population, as it were, before it has been reduced to an entirely inert phase and so have their link also with the biological life of the soil. That there must be some such passage of matter on a biological basis is suggested by the fact that only in fertile soil, i.e. in soils teeming with bacteria, do these non-mycorrhiza formers reveal resistance to disease and high quality in the produce, which means that only in these soils are they really properly fed.

This would be a third method used by plants for feeding themselves, a sort of half-way method between the absorption powers exercised by the root hairs and the direct digestive capacity of the roots: as the mechanism used in this method is presumably the root hairs, the diffuseness of the root system of plants of the cabbage family would be explained. It is possible that even mycorrhiza formers use this alternative passage for organic nitrogen. There seems no reason at all why this should not be so.

But how do the various agencies concerned in these intricate operations manage to carry on their work, buried as they are away from the light and thus unable to derive anything from the source of energy, the sun? How do they do their initial work at all until they can hand over to the green leaf? They derive their energy by oxidising (i.e. burning up) the stores of organic matter in the soil. As in an ordinary fire, this process of oxidation releases energy. The oxygen needed for this slow combustion is drawn from the air, in part washed down by the rain, which dissolves it from the atmosphere in its descent. Incidentally this explains why rain is so superior as a moistening agency for plants to any form of watering from a can: incidentally, again, we can understand the need for cultivating the soil and keeping it open, so that the drawing in of oxygen, or the respiration of the soil, can proceed and the excess carbon dioxide can be expelled into the atmosphere.

Humus is the Latin word for soil or earth. But as used by the husbandman humus nowadays does not mean just earth in general, but indicates that undecayed residue of vegetable and animal waste lying on the surface, combined with the dead bodies of these bacteria and fungi themselves when they have done their work, the whole being a highly complex and somewhat varying substance which is, so to say, the mine or store or bank from which the organisms of the soil and then, in direct succession, the plant, the tree, and thereafter the animal draw what they need for their existence. This store is all important.

THE SIGNIFICANCE OF HUMUS

Humus is the most significant of all Nature's reserves and as such deserves a detailed examination.

A very perfect example of the methods by which Nature makes humus and thus initiates the turning of her Wheel is afforded by the floor of the forest. Dig down idly with a stick under any forest tree: first there will be a rich, loose, accumulation of litter made up of dead leaves, flowers, twigs, fragments of bark, bits of decaying wood, and so forth, passing gradually as the material becomes more tightly packed into rich, moist, sweet-smelling earth, which continues downwards for some inches and which, when disturbed, reveals many forms of tiny insect and animal life. We have been given here a glimpse of the way Nature makes humus--the source from which the trunk of the tree has drawn its resisting strength, its leaves their glittering beauty.

Throughout the year, endlessly and continuously, though faster at some seasons than at others, the wastes of the forest thus accumulate and at once undergo transformation. These wastes are of many kinds and mix as they fall; for leaf mingles with twig and stem, flower with moss, and bark with seed-coats. Moreover, vegetable mingles with animal. Let us beware of the false idea that the forest is a part of the vegetable kingdom only. Millions of animal existences are housed in it; mammals and birds are everywhere and can be seen with the naked eye. The lower forms of animal life--the invertebrates--are even more numerous. Insects, earthworms, and so forth are obvious: the microscope reveals new worlds of animal life down to simple protozoa. The excrete of these animals while living and their dead bodies constitute an important component of what lies on the forest floor; even the bodies of insects form in the mass a constituent element not without importance, so that in the end the two sources of waste are completely represented and are, above all, completely mingled. But the volume of the vegetable wastes is several times greater than that of the animal residues.

These wastes lie gently, only disturbed by wind or by the foot of a passing animal. The top layer is thus very loose; ample air circulates for several inches downwards: the conditions for the fermentation by the moulds and microbes (which feed on the litter) are, as the scientist would say, aerobic. But partly by pressure from above and partly as the result of fermentation the lower layers are forced to pack more closely and the final manufacture of humus goes on without much air: the conditions are now anaerobic. This is a succession of two modes of manufacture which we shall do well to remember, as in our practical work it has to be imitated (p. 198).

This mass of accumulated wastes is acted on by the sunlight and the rain; both are dispersed and fragmented by the leaf canopy of the trees and undergrowth. The sunlight warms the litter; the rain keeps it moist. The rain does not reach the litter as a driving sheet, but is split up into small drops the impetus of whose fall is well broken. Nor does the sunlight burn without shade; it is tempered. Finally, though air circulates freely, there is perfect protection from the cooling and drying effects of strong wind.

With abundant air, warmth, and water at their disposal the fungi and bacteria, with which, as we have already noted, the soil is teeming, do their work. The fallen mixed wastes are broken up; some passes through the bodies of earthworms and insects: all is imperceptibly crumbled and changed until it decomposes into that rich mass of dark colour and earthy smell which is so characteristic of the forest 'door and which holds such a wealth of potential plant nourishment.

The process that takes place in a prairie, a meadow, or a steppe is similar; perhaps slower, and the richness of the layer of humus will depend on a good many factors. One, in particular, has an obvious effect, namely, the supply of air. If, for some reason, this is cut off, the formation of humus is greatly impeded. Areas, therefore, that are partly or completely waterlogged will not form humus as the forest does: the upper portion of the soil will not have access to sufficient free oxygen, nor will there be much oxygen in the standing water. In the first case a moor will result; in the second a bog or morass will be formed. In both these the conditions are anaerobic: the organisms derive their oxygen not from the air but from the vegetable and animal residues including the proteins. In this fermentation nitrogen is always lost and the resulting low-quality humus is known as peat.

But the forest, the prairie, the moor, and the bog are not the only areas where humus formation is in progress. It is constantly going on in the most unlikely places--on exposed rock surfaces, on old walls, on the trunks and branches of trees, and indeed wherever the lower forms of plant life--algae, lichens, mosses, and liverworts--can live and then slowly build up a small store of humus.

Nature, in fact, conforming to that principle of reserves, does not attempt to create the higher forms of plant life until she has secured a good store of humus. Watch how the small bits of decayed vegetation fall into some crack in the rock and decompose: here is the little fern, the tiny flower, secure of its supply of food and well able to look after itself, as it thrusts its roots down into the rich pocket of nourishment. Nature adapts her flora very carefully to her varying supplies of humus. The plant above is the indicator of what the soil below is like, and a trained observer, sweeping his eye over the countryside, will be able to read it like the pages of a book and to tell without troubling to cross a valley exactly where the ground is waterlogged, where it is accumulating humus, where it is being eroded. He looks at the kind and type of plant, and infers from their species and condition the nature of the soil which they at once cover and reveal.

But we are not at the end of the mechanisms employed by Nature to get her great Wheel to revolve with smooth efficiency. The humus that lies on the surface must be distributed and made accessible to the roots of plants and especially to the absorbing portions of the roots and their tiny prolongations known as root hairs--for it is these which do the delicate work of absorption. How can this be done? Nature has, perforce, laid her accumulation on the surface of the soil. But she has no fork or spade: she cannot dig a trench and lay the food materials at the bottom where the plant root can strike down and get them. It seems an impasse, but the solution is again curiously simple and complete. Nature has her own labour force--ants, termites, and above all earthworms. These carry the humus down to the required deeper levels where the thrusting roots can have access to it. This distribution process goes on continually, varying in intensity with night and day, with wetness or dryness, heat or cold, which alternately brings the worms to the surface for fresh supplies or sends them down many feet. It is interesting to note how a little heap of leaves in the garden disappears in the course of a night or two when the earthworms are actively at work. The mechanism of humus distribution is a give and take, for where a root has died the earthworm or the termite will often follow the minute channel thus created a long way.

Actually the earthworm eats of the humus and of the soil and passes them through its body, leaving behind the casts which are really enriched earth--perfectly conditioned for the use of plants. Analyses of these casts show that they are some 40 per cent richer in humus than the surface soil, but very much richer in such essential food materials as combined nitrogen, phosphate, and potash. Recent results obtained by

Lunt and Jacobson of the Connecticut Experiment Station show that the casts of earthworms are five times richer in combined nitrogen, seven times richer in available phosphate, and eleven times richer in potash than the upper six inches of soil.

It is estimated that on each acre of fertile land no less than twenty-five tons of fresh worm casts are deposited each year. Besides this the dead bodies of the earthworms must make an appreciable contribution to the supply of manure. In these ways Nature in her farming has arranged that the earth itself shall be her manure factory.

As the humus is continually being created, so it is continually being used up. Not more than a certain depth accumulates on the surface, normally anything from a few inches to two or three feet. For after a time the process ceases to be additive and becomes simply continuous: the growing plants use up the product at a rate equalling the rate of manufacture--the even turning of the Wheel of Life--the perfect example of balanced manuring. A reserve, however, is at all times present, and on virgin and undisturbed land it may be very great indeed. This is an important asset in man's husbandry; we shall later see how important.

THE IMPORTANCE OF MINERALS

Is the humus the only source from which the plant draws its nourishment? That is not so. The subsoil, i.e. that part of the soil derived from the decay of rocks, which lies below the layer of humus, also has its part to play. The subsoil is, as it were, a depository of raw material. It may be of many types, clay, sand, etc.; the geological formation will vary widely. It always includes a mineral content--potash, phosphates, and many rarer elements.

Now these minerals play an important part in the life of living things They have to be conveyed to us in our food in an organic form, and it is from the plant, which transforms them into an organic phase and holds them thus, that we and the other animals derive them for our well-being.

How does the plant obtain them? We have seen that there is a power in the roots of all plants, even the tiniest, of absorbing them from the soil solution. But how is the soil solution itself impregnated with these substances? Mainly through the dissolving power of the soil water, which contains carbon dioxide in solution and so acts as a weak solvent. It would appear that the roots of trees, which thrust down into the subsoil, draw on the dissolved mineral wealth there stored and absorb this wealth into their structure. In tapping the lower levels of water present in the subsoil--for trees are like great pumps drawing at a deep well--they also tap the minerals dissolved therein. These minerals are then passed into all parts of the tree, including the foliage. When in the autumn the foliage decays and falls, the stored minerals, now in an organic phase, are dropped too and become available on the top layers of the soil: they become incorporated in the humus. This explains the importance of the leaf-fall in preserving the land in good heart and incidentally is one reason why gardeners love to accumulate leaf-mould. By this means they feed their vegetables, fruit, and flowers with the minerals they need.

The tree has acted as a great circulatory system, and its importance in this direction is to be stressed. The destruction of trees and forests is therefore most injurious to the land, for not only are the physical effects harmful--the anchoring roots and the sheltering leaf canopy being alike removed--but the necessary circulation of minerals is put out of action. It is at least possible that the present mineral poverty of certain tracts of the earth's surface, e.g. on the South African veldt, is due to the destruction over wide areas and for long periods of all forest growth, both by the wasteful practices of indigenous tribes and latterly sometimes by exploiting Western interests.

SUMMARY

Before we turn to consider the ways in which man has delved and dug into all these riches and disturbed them for his own benefit, let us sum up with one final glance at the operations of Nature. Perhaps one fact will strike us as symptomatic of what we have been reviewing, namely, the enormous care bestowed by Nature on the processes both of destruction and of storage. She is as minute and careful, as generous in her intentions, and as lavish in breaking down what she has created as she was originally in building it up. The subsoil is called upon for some of its water and minerals, the leaf has to decay and fall, the twig is snapped by the wind, the very stem of the tree must break, lie, and gradually be eaten away by minute vegetable or animal agents; these in turn die, their bodies are acted on by quite invisible fungi and bacteria; these also die, they are added to all the other wastes, and the earthworm or ant begins to carry this accumulated reserve of all earthly decay away. This accumulated reserve--humus--is the very beginning of vegetable life and therefore of animal life and of our own being. Such care, such intricate arrangements are surely worth studying, as they are the basis of all Nature's farming and can be summed up in a phrase--the Law of Return.

We have thus seen that one of the outstanding features of Nature's farming is the care devoted to the manufacture of humus and to the building up of a reserve. What does she do to control such things as insect, fungous, and virus diseases in plants and the various afflictions of her animal kingdom? What provision is to be found for plans protection or for checking the diseases of animals? How is the work of mycologists, entomologists, and veterinarians done by Mother Earth? Is there any special method of dealing with diseased material such as destruction by fire? For many years I have diligently searched for some answer to these questions, or for some light on these matters. My quest has produced only negative evidence. There appears to be no special natural provision for controlling pests, for the destruction of diseased material, or for protecting plants and animals against infection. All manner of pests and diseases can be found here and there in any wood or forest; the disease-infected wastes find their way into the litter and are duly converted into humus. Methods designed for the protection of plants and animals against infection do not appear to have been provided. It would seem that the provision of humus is all that Nature needs to protect her vegetation; and, nourished by the food thus grown, in due course the animals look after themselves.

In their survey of world agriculture--past and present--the various schools of agricultural science might be expected to include these operations of Nature in their teaching. But when we examine the syllabuses of these schools, we find hardly any references to this subject and nothing whatever about the great Law of Return. The great principle underlying Nature's farming has been ignored. Nay more, it has been flouted and the cheapest method of transferring the reserves of humus (left by the prairie and the forest) to the profit and loss account of homo sapiens has been stressed instead. Surely there must be something wrong somewhere with our agricultural education.

CHAPTER III

SYSTEMS OF AGRICULTURE

What is agriculture? It is undoubtedly the oldest of the great arts; its beginnings are lost in the mists of man's earliest days. Moreover, it is the foundation of settled life and therefore of all true civilization, for until man had learnt to add the cultivation of plants to his knowledge of hunting and fishing, he could not emerge from his savage existence. This is no mere surmise: observation of surviving primitive tribes, still in the hunting and fishing stage like the Bushmen and Hottentots of Africa, show them unable to progress because they have not mastered and developed the principle of cultivation of the soil.

PRIMITIVE FORMS OF AGRICULTURE

The earliest forms of agriculture were simple processes of gathering or reaping. Man waited until Nature had perfected the fruits of the earth and then seized them for his own use. It is to be noted that what is intercepted is often some form of Nature's storage of reserves; more especially are most ripe seeds the perfect arsenals of natural reserves. Interception may, however, take other forms. A well-developed example of human existence based on a technique of interception is the nomadic pastoral tribe. Pastoral peoples are found all over the world; they have played some part in the history of the human race and often exhibit an advanced degree of culture in certain limited directions, not only material. Their physical existence is sustained on what their flocks and herds produce. To secure adequate grazing for their animals they wander, sometimes to and fro between recognized summer and winter pastures, sometimes over still greater distances. In this way they intercept the fresh vegetable growths brought to birth season by season out of the living earth; however successful, it is nothing more than a harvesting process.

It is presumed rather than known that at some period man extended his idea of harvesting to the gathering of the heads of certain plants, thus adding a vegetable element to the milk, meat, and fish he had been deriving from his animals and the chase. Wild barley, rice, and wheat are all supposed to have been gathered in this way in different parts of the earth. But real agriculture only began when, observing the phenomenon of the germination of seeds, instead of consuming all that they had gathered, men began to save some part of what they had in store for sowing in the ground. This forced them to settlement, for they had to wait until the plants grew from the seed and matured.

If at first the small store of gathered seed was sown in any bare and handy patch, the convenience of clearing away forest growths so as to extend the space for sowing soon became apparent. The next stage was to prepare the ground thus won. The art of tillage has progressed over the centuries. The use of a pointed stick drawn through the ground is still quite common. The first ploughs were drawn by human labour--a practice which survived even in such countries as Hungary and Romania into the nineteenth century. But the use of animals, tamed for their muscular strength to replace the human team, became the normal and world-wide practice, until ousted in certain continents first by the still more powerful steam engine and now by the internal combustion engine.

What was the purpose of this tillage, which is still the prime agricultural process? The first effect is, of course, physical. The loosened soil makes room for the seed, which thus can grow in abundance, while to cover the sowing with scattered earth or to press it into the ground protects it from the ravages of birds or insects. Secondly, tillage gives access to the air--and the process of soil respiration starts up, followed by the nitrification of organic matter and the production of soluble nitrates. The rain, too, can penetrate better. In this way physical, biological, and chemical effects are set in motion and a series of lively physiological changes and transformations result from the partnership between soil and plant. The soil produces food materials: the plants begin to grow: the harvest is assured: the sowing has become a crop.

Yet this is not the way in which Nature is accustomed to work. She does not, as a rule, collect her plants, the same plants, in one spot and practice monoculture, but scatters them: her mechanisms for scattering seed are marvellous and most effective. Man's habit, so convenient, of collecting a specified seed and sowing it in a specified area implies, it must be acknowledged, a definite interference with Nature's habits. Moreover, by consuming the harvest and thus removing it from the place where it had grown he for the time being interrupts the round of natural processes.

In fact, man has laid his hand on the great Wheel and for a moment has stopped or deflected its turning. To put it in another way, he has for his own use withdrawn from the soil the products of its fertility. That man is entitled to put his hand on the Wheel has never been doubted, except by such sects as the Doukhobors who argued themselves into a state of declaring it a sin to wound the earth with spades or tools. But if he is to continue to exist, he must send the Wheel forward again on its revolutions. This is a necessary part of all primitive cultivation practices and perhaps a tenet of all true early religions as soon as they lift themselves from the stages of mere animism or fetish worship; at any rate, all the great agricultural systems which have survived have made it their business never to deplete the earth of its fertility without at the same time beginning the process of restoration. This becomes a veritable preoccupation.

SHIFTING CULTIVATION

The simplest way of doing this is after a time to leave the cultivated patch and thus stop the process of interference. Nature will overrun it again with scrub or forest: soon the green carpet is re-established: in due course humus will accumulate: it will be as it was--the earth's fruitfulness will be restored. To pass on, therefore, from one patch to another, and again to another and another, is a common primitive practice found in Africa, India, Ceylon, and many other parts of the world, and is known as shifting cultivation. It even occurred in the American continent some ten years or so ago before the Tennessee Valley Authority was constituted by the late President of the United States of America. In this shifting cultivation the fresh patch is usually cleared by burning the jungle: this leaves the ash in situ, and thus retains some of the mineral contents of the burnt vegetation for the benefit of the coming crop. But it is a wasteful method, for a large aggregate area is required to feed a small group, while a long period has to be reckoned to replace the lost fertility. Indeed, this replacement is seldom consummated. The larger trees suffer, the best part of the forest is virtually destroyed. It will also be observed that after using up the riches of the soil man actually does nothing to restore it--he merely leaves it. This lazy practice constitutes the least satisfactory of many agricultural systems and, entailing constant small movements of working area on the part of those practicing it, is no foundation for a settled civilization. It does, however, show that primitive tribes not only realized the fact that fertility can be exhausted, but also understood how it could be restored.

THE HARNESSING OF THE NILE

A much more satisfactory method of restoring soil fertility was evolved in the great river valley of the Nile which, according to some theorists, was the original home of agriculture proper. It is the peculiarity of this great river that it overflows once a year with great regularity, bearing suspended in its flood an accumulation of fertile silt washed down from its catchment basin; this accumulation, rich in both mineral and organic matter, is gently deposited and is capable of yielding an abundant harvest. The process continued for centuries. Early engineering skill led the silt-laden water to embanked fields by means of inundation canals. The deposit was trapped just where it was needed and the land was at the same time saturated with water. When the embanked fields were dry enough, they were ploughed and sown: no rain fell and no more water was needed for a full crop. The annual additions of rich silt made this method of farming permanent. In this way there grew up settled habitations, a great civilization, an historic people.

This basin system of irrigation in Egypt, which is perhaps the best and most permanent that can be devised, has of recent years been replaced by another--perennial irrigation--by which the same field can be watered periodically to allow of cotton being grown. For this purpose the Nile has been impounded and a vast reservoir has been created for feeding the canals. But unless the very greatest care is taken to restore and then to maintain the compound soil particles by means of constant dressings of freshly prepared humus these modern methods are doomed. The too frequent flooding of the close silts of this river valley will lead to the formation of alkali salts and then to the death of the soil. This will be the fate of Egypt if the powers-that-be persist in the present methods of cultivation of cotton and do not realize before it is too late that their ancient system of irrigation is, after all, the best.
Will a few years of cotton growing make up for the loss of the soil on which the yew, life of Egypt is based? On the answer to this question the future of the Nile valley will depend.

STAIRCASE CULTIVATION

Few areas on the earth's surface are so fortunate. What the great river bestowed on the lucky Egyptians has had to be created in other parts of the world, sometimes in the most unpromising conditions. The so-called staircase cultivation of the ancient Peruvians is regarded as one of the oldest forms of agriculture known to us--it dates from the Stone Age. Without metal tools this people could not remove the dense forest growths of the humid South American valleys. They were driven to the upland areas under grass, scrub, or stone. Here they constructed terraced fields up the slopes of the mountains, tier upon tier, sometimes as many as fifty tiers rising one above the other. The outer retaining walls of these terraces were made of large stones fitted into each other with such accuracy that even at the present day a knife blade cannot be inserted between them. Inside these walls were laid coarse stones and over these clay, then layers of soil several feet thick, all of which had to be imported from beyond the mountains. Just sufficient slope was given to each tiny field for watering, water also being brought in stone aqueducts from immense distances--one aqueduct of between 400 and 500 miles has been found traversing the mountain slope many hundreds of feet above the valley. Thus a series of gigantic flower pots were formed and in these were grown the crops to nourish a nation and to establish a civilization.

The results of such incredible labour are still to be seen, but the Inca nation itself has vanished. However, in the Hunzas living in a high mountain valley of the Gilgit Agency on the Indian frontier we have an existing demonstration of what a primitive system of agriculture can do if the basic laws of Nature are faithfully followed. The Hunzas are described as far surpassing in health and strength the inhabitants of most other countries; a Hunza can walk across the mountains to Gilgit sixty miles away, transact his business, and return forthwith without feeling unduly fatigued. In a later chapter we shall point to this as illustrative of the vital connection between a sound agriculture and good health. The Hunzas have no great area from which to feed themselves, but for thousands of years they have evolved a system of farming which is perfect. Like the ancient Peruvians they have built stone terraces, whose construction admits of admirable soil drainage and therefore of admirable soil aeration--for where water drains away properly air is abundantly drawn in. As in the ancient Peruvian system, irrigation is employed to obtain the water and it is not without interest that this water is glacier water bringing down continual additions of fine silt ground out from the rocks by the great cap of ice. It is probable, though it has not been investigated, that the mineral requirements of the fields are thus replenished to a remarkable degree. To provide the essential humus every kind of waste, vegetable, animal, and human, is mixed and decayed together by the cultivators and incorporated into the soil; the law of return is obeyed, the unseen part of the revolution of the great Wheel is faithfully accomplished.

THE AGRICULTURE OF CHINA

It is this return of all wastes to the soil, including the mud of ponds, canals, and ditches, which is the secret of the successful agriculture of the Chinese. The startling thing to realize about this peasant nation of over four hundred million souls is the immense period of time over which they have continued to cultivate their fields and keep them fertile, at least 4,000 years. This is indeed a contrast to the shifting cultivation of the African and it may be observed here that the greatest misfortune of the African continent has been that it never came into contact with the agricultural peoples of the Far East and never revised its systems of cultivation in the light of the knowledge it might thereby have gained--the great lesson of the Nile basin was not truly apprehended and has had no influence outside Egypt, whereas over large parts of eastern Asia the central problem of agriculture was solved very early, empirically and not by a process of scientific investigation, yet with outstanding success.

The Chinese peasant has hit on a way of supplying his fields with humus by the device of making compost. Compost is the name given to the result of any system of mixing and decaying natural wastes in a heap or pit so as to obtain a product resembling what the forest makes on its floor: this product is then put on the fields and is rich in humus. The Chinese pay great attention to the making of their compost. Every twig, every dead leaf, every unused stalk is gathered up and every bit of animal excrete and the urine, together with all the wastes of the human population, are incorporated. The device of a compost heap is clever. By treating this part of the revolution of the Wheel as a special process, separated from the details of cultivation, time is gained, for the wastes mixed in a heap and kept to the right degree of moisture decay very quickly, and successive dressings can be put on the soil, which thus is kept fed with just what it needs: there is no pause while the soil itself manufactures from the raw wastes the finished humus. On the contrary, everything being ready and the humus being regularly renewed at frequent intervals, the soil is able to feed an uninterrupted succession of plants, and it is a feature of Chinese cultivation that one crop follows another without a pause, indeed crops usually overlap, the ripe crop being skilfully removed by hand from among the young growing plants of the succeeding planting or sowing. In short, what the Chinese farmer really does is ingeniously to extend his area. He, so to say, rolls up the floor of the forest and arranges it in a heap. The great processes of decay go on throughout that heap, spreading themselves over the whole of the internal surface of the heap, that is, over the whole of the surfaces implied in the juxtaposition of every piece of waste against every other. He also overcomes the smallness of the superficial area of his holding by increasing the internal surface of the pore spaces of his soil. This is what matters from the point of view of the crop--the maximum possible area on which the root hairs can collect water and food materials for the green leaf. To establish and to maintain this maximum pore space there must be abundant humus, as well as a large and active soil population.

Thus is created the most intensive agriculture which the world has so far seen. Each Chinese family lives on the produce of a very tiny piece of ground, an area which would mean downright starvation in most other countries. In spite of great calamities which repeat themselves, principally floods, the causes of which will be mentioned hereafter, the Chinese peasant may be said to be, on the whole, well nourished. His resisting power to the many frightful diseases, sufficient to kill off most other populations, has been noted, while the standard of culture which he has reached and has maintained over the long period of his existence rivals the contributions of Western civilization.

He is indeed the classic example of a nation which has conserved the fertility of its soil. Other nations have done the same, but none over so long a period or on so vast an area. Is it legitimate to interpret the history of the nations by the way in which they have made use of the land which chance or their own velour assigned to them? We have considered some instances where attempts have been made to conserve fertility with greater or lesser success. Let us now turn to some different examples.

THE AGRICULTURE OF GREECE AND ROME

The agricultural history of the ancient Greeks is not altogether clear. But one thing is certain: in common with most other Mediterranean peoples they permitted an extraordinary amount of destruction of forest growths over some of the areas bordering on this great inland sea. Greece is now a land bare of trees and the continued depredations of the goat have done untold harm to any young growths that have attempted to survive. Whether this process began on a large scale very early and whether the result was a severe disturbance of the drainage of a not very fruitful country, extending on the one hand the area of marsh and on the other inviting erosion, is not certain. Such conditions would affect first the crops and then those who fed off them--subtle forms of undernourishment and disease would appear. The theory has been put forward that the extraordinary and unexplained collapse of the Greek nation in the fourth and third centuries B.C., after a period of the highest vigour and culture, was due to the spread of malaria. It is a theory which is very reasonable and would explain much.

The case of the Romans, another Mediterranean people, is not quite the same. For many centuries they maintained a flourishing agriculture to which they paid great attention. The backbone of the nation throughout its greatest period was the staunch mass of smallholders, each engaged on cultivating his own farm and only breaking off at intervals to pursue political matters with great vigour or to fight short summer campaigns with the utmost zest. In spite of the attractions of the metropolis and of the wonderful educational influence with which city life shaped law, thought, and conduct, the rural background was conserved and valued; religion remained rather rural throughout and never got very much beyond the peasant outlook. It was the necessity for fighting prolonged foreign campaigns which destroyed all this. Then came the fatal attractions of slave labour. The smallholder was tempted or indeed was obliged to desert his holding for years. Such holdings began to be bought up, for wealth accumulated from the spoils of the East. Slaves were drafted in to work these agglomerations of great estates: the evil latifundium, which means the plantation in its worst form, spread everywhere. The final phase was reached when tillage was given up for the cheaper pastoral industry: where there had been countless flourishing homesteads now ranged great herds of cattle tended by a few nomadic shepherd slaves.

This disastrous change, which was deeply deplored by such writers as Cicero, lasted and, except in northern Italy, was not made good. A few years ago it was possible to see on a mere day's excursion away from Rome a wild shepherd tending his sheep over a ruined countryside which might have been carved out of the most ancient of wildernesses, so entirely was it denuded of all traces of tillage or of the care of man. There must have been some profound upsetting of the balanced processes of Nature to reduce so fertile a country as Italy to such a state and Nature in revenge has preferred to continue her revolution of the Wheel on the lowest gear, spreading her marsh, her scrub, and her desert, where once there were fields and meadows.

Having largely destroyed the food-bearing capacity of the Italian peninsula, the Romans were forced to feed their swollen cities from elsewhere. For the dispossessed rural population drifted to the towns, which became further congested with a great influx of foreigners and foreign slaves: all had to be fed, and Alexandria and Antioch were problems no less great than Rome. First Sicily and then North Africa, at that time great wheat-growing countries, were exhausted. We cannot trace the process and do not know how much to attribute to a false economy, how much to the ravages of centuries of war, as wave after wave of conquerors disputed possession. When these countries reappear after such cataclysms, Sicily is a wild pastoral country, North Africa, except for a few coastal tracts and, of course, always Egypt, a desert.

FARMING IN THE MIDDLE AGES

The rest of the continent of Europe was more fortunate. Out of the lingering shadows of the Roman Empire there finally emerged into medieval times a system of agriculture which held its own well into the nineteenth century. Such a long history is an honourable one and we may agree that this system, that of mixed husbandry, was in many essentials excellent. Except where a frozen legal system ground down the cultivator--'trembling peasants gathering piteous harvests'--both the large farm and the smallholding, the landlord and the tenant, survived in good health and considerable comfort. Food was abundant and nourishing, and above all the soil remained in good heart.

The system depended on certain principles. In the first place, animal husbandry was practiced alongside of the production of vegetable crops: there was thus a supply of manure. The manure was not made on the most perfect system. The European manure heap, normally regarded as the inevitable method of collecting and storing animal wastes, is nevertheless most inefficient, as will be pointed out in a later chapter (p. 192). But it has played a prime role in maintaining the fertility of our continent, although it is wasteful and extravagant, unhealthy, and unnatural: with the help of the manure heap the return of much of the wastes of farming was assured to the land.

The use of the cesspit was even less successful and it is not surprising that water-borne sewage, when once invented, rapidly replaced it: unfortunately this permitted the final escape of valuable wastes to the sea. To this came to be added, also in the course of the nineteenth century, the further loss of all dustbin refuse which, again on the dictates of the new sanitary science, was destroyed by burning or was buried in unused tips. Nevertheless, until these modern sewage disposal methods were developed, it is significant that all material wastes went back to the soil in however imperfect a way.

A third principle in conserving fertility was the fallow. Arable land was rested by allowing it to remain idle for a year or for a longer period by the establishment of a temporary carpet of grass and weeds. A part at least of the advantage of the bare fallow was the benefit conferred by the weeds. When laid down to grass for sheep, the green carpet rapidly deposited a mass of vegetable wastes under the turf which, with the turf and the animal wastes deposited thereon, provided all the raw materials for sheet-composting when the land came under the plough. Both these methods have been employed in European farming for many centuries and did much to conserve the fertility of the soil.

As long as all these principles governed European farming it could roughly hold its own, although a slow running down of soil fertility remained at all times a possibility, as will be seen in the next chapter. It began to break down seriously with the advent of the Industrial Revolution. But before dealing with the changes thus brought about in European agriculture it will be illuminating to examine in greater detail the story of one people, our own, in terms of the use made by the community of soil fertility. We shall see that, in spite of the great and advantageous practices to which we have alluded, soil fertility was subtly and gradually used up. This has determined much in our national affairs.

CHAPTER IV

THE MAINTENANCE OF SOIL FERTILITY IN GREAT BRITAIN

Many accounts of the way the present system of farming in Great Britain has arisen have been published. The main facts in its evolution from Saxon times to the present day are well known. Nevertheless, in one important respect these surveys are incomplete. Nowhere has any attempt been made to bring out the soil fertility aspect of this history and to show what has happened all down the centuries to that factor in crop production and animal husbandry--the humus content of the soil--on which so much depends. The present chapter should be regarded as an attempt to make good this omission.

THE ROMAN OCCUPATION

At the time of the Roman invasion most of the island in which we are living was under forest or marsh: only a portion of the uplands was under grass or crops: the population was very small. After the conquest of the country the Romans began to develop it by the creation on the areas already cleared of an agricultural unit--new to Great Britain--known as the villa. These villas were large farms under single ownership run by functionaries each responsible for a particular type of animal or crop and worked by slave labour. These units followed to some extent the methods of the latifundia of Italy and were designed for the production of food for the legions garrisoning the island and those stationed in Gaul. Wheat--an exhausting crop--was an important item in Roman agriculture, for the reason that this cereal provided the chief food (frumentum) of the soldiers. The extent of the export of grain to Gaul will be evident from the fact that in the reign of the Emperor Julian no less than 800 wheat ships were sent from Britain to the Continent.

The exhaustion of the soils of the island began even before the Roman occupation. The heavy soil-inverting mould board plough, which invariably wears out the land, was already in use when the Romans arrived, and was probably brought by the Belgic tribes who conquered and settled in the south-eastern part of the country. They lived in farmsteads and cultivated large open fields. They were highly skilled agriculturists and exported to Gaul a considerable quantity of their main product--wheat. This practice was developed by the Roman villas which followed and in this way the slow exhaustion of the lighter soils of the downlands of the south-east became inevitable.

After an occupation which lasted some 400 years and which contributed little or nothing of permanent value to the agriculture of the island beyond some well-designed roads, the legions evacuated the island and left the Romanized population to look after itself. This they failed to do: the country was soon conquered by the Saxon invaders, in the course of which much destruction of life and property took place. One result was the creation of a new type of farming.

THE SAXON CONQUEST

The settlement of Nordic people in our island is the governing event both of British history and of British agriculture. The new settlers had inhabited the belts of land around the Weser and the Elbe and their first contact with Britain was as raiders; their operations were in the nature of reconnaissance to ascertain the chances of settlement. The Anglo-Saxon migration to Britain was a colonization preceded by conquest, in which the farming system of the Romanized population was, in the midland area at any rate, destroyed. In the east, south-east, and western portions of the island some relics of Roman and Celtic methods survived.

Our forefathers brought with them from the opposite shores of the North Sea their wives, children, livestock, and a complete fabric of village life. The immigrants, being country folk, wanted to live in rural huts with their cattle round them and their land nearby, as they did in Germany. The numerous villages they formed reproduced in all essentials those they had left behind on the mainland. Our true English villages are, therefore, not Celtic, are not Roman, but purely and typically German.

The Roman villas were replaced by a new system of farming--the Saxon manor--in which the tenants held land in return for service. The lord and his retainers shared the land, each bound to perform certain duties determined by custom. The manors took centuries to evolve. By A.D. 800 they had developed into a permanent system which provided the material for the Domesday Book of the Normans, by which taxation was assessed and a rigid feudal system became firmly established.

THE OPEN-FIELD SYSTEM

The first general feature that strikes us in early Anglo-Saxon England is the strip cultivation of the arable land on the open-field system. This system was a communal agricultural institution started by people who had to get a living out of the soil. They had progressed as far as to use the plough and had a common fund of experience. Everyone pursued the same system of farming. The arrangement of the open fields was, however, by no means uniform. No fewer than three distinct types arose, corresponding to as many different influences exerted by people who had early occupied the country. The large central midland area, stretching from Durham to the Channel and from Cambridgeshire to Wales, is the region where Germanic usage prevailed. The south-east was characterized by the persistence of Roman influence, a circumstance which implies that the conquest was less destructive there than in the north and west. The counties of the south-west, north-west, and the north retained Celtic agrarian usages in one form or another, which is easily understood in view of the difficulty with which, as we know, these districts were slowly overpowered by the invaders. The midland area was thus the region where the Anglo-Saxons were most firmly established and where the subjugation of the fifth century was most thorough. The Romano-Celtic people who remained were not numerous enough to preserve any traces of Roman or Celtic methods of tilling the soil.

Throughout this extensive region a two-field and a three-field system, or sometimes a mixture of the two, prevailed. This field arrangement was a custom prevalent in Germany, especially east and south of the Weser. The chief characteristic of the two-and three-field type of tillage was the distribution of the parcels of arable land (which made up the holdings of the customary tenants) equally amongst the two or three fields. The cropping was so arranged that one field in the two-field system and two fields in the three-field system were cropped every year, and thus one-half or one-third of the township's arable land lay fallow and was used for common grazing--a point which is always emphasized in the midland system.

Besides the cultivated open fields, for which the best land was always used, the village lands consisted of grassland for mowing on the wetter parts, and commons or woodlands on the poorer parts.

Ploughing was the all-important operation of medieval tillage and was carried out on a co-operative basis, and demanded a team of eight draught animals yoked to a heavy plough. This, of course, was beyond the reach of any but the largest and most prosperous tenants. Communal ploughing in Saxon times was, therefore, inevitable. It was the difficulty of replacing this communal ploughing that delayed agricultural progress in many parts of the country.

The open-field system repeated itself for centuries, not only in England but in a great part of Europe--nations living under very different conditions, in very different climates, and on very different soils adopted the open-field system again and again without having borrowed it from each other. This could not but proceed from some pressing necessity. The open-field system is communal in its very essence. Every trait which makes it strange and inconvenient from the point of view of individualistic interests renders it highly appropriate to a state of things ruled by communal conceptions--right of common usage--communal arrangements of ways and time of cultivation. These are the main features of open-field husbandry and all point to one origin--the formation in early Anglo-Saxon society of a village community of shareholders of free and independent growth.

It must be borne in mind that the open-field prevailed during the period of national formation of the English people and its influence on the life of the village community must have been very great. The sense of personal responsibility, which the system of communal work created, made it a vital factor in the social education of the people.

THE DEPRECIATION OF SOIL FERTILITY

Open-field farming is, as a rule, balanced: the fertility used up in growth is made good before the next crop is sown. Compared with our modern standards, however, the yield is remarkably low and the removal of fertility by such small crops is made up for by the recuperative processes operating in the soil (non-symbiotic fixation of nitrogen and so forth). The surplus of available humus originally left by the forest is depleted at an early stage and an equilibrium is established, the yield adjusting itself to the amount of fertility added each year by natural processes, this in its turn is influenced by climate and methods of cultivation.

For example, in the peasant cultivation of north-west India at the present day a perfect balance has been established between losses and gains of fertility. The village land on which corn crops are grown has been cultivated for upwards of 2,000 years without manure beyond the droppings of the livestock during the fallow period between harvest and the rains. But the Indian cultivators use primitive scratch ploughs and are most careful not to draw on the reserves of organic material in the soil, as its texture depends on this. They produce crops entirely on the current account provided by the annual increments of fertility. The yield has settled down to 8 maunds (658 lb. per acre) of wheat on unirrigated land, and 12 maunds (987 lb.) of wheat on irrigated land, and this yield has been constant for many centuries.

The same processes were operating in the English open fields. The reserve of humus in the soils originally under forest, which the Saxons brought into cultivation, was soon used up and the yield was determined by the annual additions of fertility to the soil by natural means. But in our cold and sunless climate and on our ill-drained, poorly aerated soils this is far less than in the semi-tropical conditions of northern India.

Moreover, and this point must be stressed, the Saxons from the earliest times used a soil-inverting plough, which has a marked tendency to exhaust the humus in the soil if provision is not made for the regular supply of sufficient farmyard manure. In fact, recent experience in many parts of the world is proving that the continued use of heavy soil-inverting, tractor-driven implements, without sufficient farmyard manure to manure the land, promptly leads to catastrophic consequences.

The first recorded references to the mould board plough speak of it in Gaul, but some authorities quoted by Vinogradoff (The Growth of the Manor) suggest that it was borrowed by the Germanic people from the Slavs, and in view of the soil types found in Slav territory this may easily be so. The evolution of the big plough was due to soil requirements as settled agricultural life developed in the heavy, moist soils of north Europe after the forests had been cleared.

The mould board plough determined the lay-out of the open fields. It divided the arable areas into a succession of lands. It needed a headland to turn on, and there was a limit to the length of furrow a team of oxen could plough before needing the relief got by stopping and turning. This furrow-long or furlong became one of our units of length. It was usual to keep the land in high ridges running along the slopes to facilitate surface drainage, an important point in England. The ridges varied in width according to the nature of the soil. In very heavy clays they were sometimes no more than three yards wide. In lighter soils they might be twenty-two yards wide. These ridges may be seen in many places to-day on grassland which was under the plough in earlier centuries. From this brief description it will be seen that the open fields cultivated with the heavy medieval plough were laid out in strips.

The main feature of the heavy mould board plough was its high penetrating power, and it could be used on the heavier types of soil where the light scratch plough of the Celts and Italians would be useless. It thus enabled the cropped area in England to be greatly extended by the cultivation of the heavy soil of the valleys and plains which first had to be slowly carved out of the forest. It owed its superiority to an iron share, a courter, and a wooden mould board so suitable on wet land. This primitive implement gave us the plough as we know it to-day. The principle of our modern plough is identical and, except for the fact that it is now made entirely of iron, it is almost the same in detail.

The open-field system of the Middle Ages was bound to fail because it involved burning the candle at both ends and also in the middle. First the natural recuperation processes in the soil were hampered by low temperatures and poor soil aeration; second, such supplies of farmyard manure as were available were by custom mostly bestowed on the lord's demesne lands, and besides were inadequate because only a portion of the livestock could be wintered; finally the soil-inverting plough led to the oxidation of the stores of soil humus faster than it could be recreated and was bound to wear out the land.

THE LOW YIELD OF WHEAT

The failure of the open-field system is proved by the low yield of wheat. All authorities agree that the yield of wheat in England during the Middle Ages was at a very low level, though it does not appear to have varied greatly. It may be noted that there was never any question of complete exhaustion of the wheat-growing land, such as occurred in Mesopotamia and in the Roman wheat-growing regions of North Africa, where the soil, owing to over-cropping and in some instances to over-irrigation aggravated by special climatic conditions, became sterile and was transformed into desert. This could not so easily happen in the moist, temperate climate of Great Britain. What happened in the Middle Ages in England was that the yield of corn was not high enough for the requirements of the growing social and economic life of the country.

The material for a quantitative estimate of wheat yields in this period is necessarily very scanty, but in the case of some large estates records are available for a considerable period of years of the seed sown in one year and the grain threshed in the following year, and these form the basis of the best estimates of medieval yields. Sir William Beveridge (Economic Journal Supplement, May 1927), using this method, investigated the yield of wheat for the years 1200 to 1450 on eight manors, including that of Wargrave, situated in seven different counties belonging to the Bishop of Winchester. The average yield per acre was 1.17 quarters or 9.36 measured bushels, equivalent to 7.48 bushels of 60 lb. It is to be noted that these estimates were all from demesne lands which were probably better cultivated and better manured than the land of the customary tenants. Other authorities confirm these figures.

The figures of yield given above help to account for the changes which marked the end of the Middle Ages. The amount of food was becoming insufficient for the growing population. But another factor was steadily developing, which finally assumed the dimensions of an avalanche and led to the reform of manorial farming. This was disease, a matter which must now be discussed.

THE BLACK DEATH

That the agriculture of the Middle Ages was unable to keep the population in health was first indicated by the frequent indications of rural unrest. But these were soon followed by the writing on the wall in the shape of the Black Death in 1348-9. This outbreak had been preceded by several years of dearth and pestilence, and it was succeeded by four visitations of similar disease before the end of the century. During its ravages it destroyed from one-third to one-half of the population. This seriously affected the labour supply, which was no longer sufficient to carry on the traditional methods of manorial farming, already beginning to be undermined by the growing tendency to replace service by money payments.

Land which could no longer be ploughed had to be laid down to grass and used for feeding sheep to produce more of the wool so urgently needed in Flanders and Lombardy. For the new farming the countryside had to be enclosed: first the lord's demesne and then the area under open fields began to be laid down to grass. The earth's green carpet not only fed the sheep, but gave the land a long rest: large reserves of humus were gradually built up under the turf: the fertility of the soil, which had been imperceptibly worn out by the mould board plough and the constant cropping of the manorial system, was gradually restored.

After a long period of rest of a century the land no longer returned only seven and a half bushels to the acre. The figures given above for the years 1200 to 1450 may be contrasted with the figures from a farm at Wargrave from 1612-20: in these years the average was 25.6 bushels of 60 lb. per acre (Beveridge, loc. cit.). In the latter part of the sixteenth century the general average was eighteen bushels to the acre and even more. That this significant change was due to the restoration of soil fertility by humus formation under the turf there can be no doubt.

It is more than probable that the slow regeneration of the soils of this country, which began after the Black Death, produced other results besides the improvement of crops and livestock. What of the effect of the produce of land in good heart on the most important crop of all--men and women? Were the outstanding achievements of the Tudor period one of the natural consequences of a restored agriculture? It may well be so.

ENCLOSURE

When increasing population led once more to the breaking up of the grassland and the farmer returned to tillage, the land, after its long rest of upwards of a century, was again capable of responding to the demands made upon it. One result of this experience was an increased interest in enclosure. Instinct was leading to a search for an economic arrangement which would prevent soil exhaustion from being repeated in succeeding ages. Enclosed farms offered a solution, as they gave the farmer the chance of keeping his land in good condition by individual management in place of the easy-going farming of the open fields of old English village agriculture. They also offered to the enclosed farmer the opportunity of composting his straw in his cattle yards and producing as much farmyard manure as possible. This, in most cases, he did, and the plan succeeded.

Nevertheless, the ancient open-field tillage husbandry had had in its favour the authority of long tradition--a potent force with a suspicious and conservative peasantry. The peasant asked himself: In the case of a readjustment of holdings would not the strong profit and the weak suffer? There grew up a popular prejudice against enclosure and the improvement of the common fields, but in the end, after some centuries of contest, enclosure won.

The form which the enclosure movement took before it was completed was due to the peculiar form of government which came in with the English Revolution of 1688. By that event the landed gentry became supreme. The national and local administration was entirely in their hands, and land, being the foundation of social and political influence, was eagerly sought by them. They not unnaturally wished to direct the enclosure movement into channels which were in the interests of their estates. But in doing so they made some of the most outstanding contributions to farming ever made in our history.

The restoration of soil fertility which resulted from enclosure had a profound influence on both livestock and crops. The provision of more and better forage and fodder which followed the cultivation of clover and artificial grasses, coupled with the popularization of the turnip crop by Townshend in 1730, opened the door for the continuous improvement of livestock by pioneers like Bakewell. The result was that our livestock improved in size and in the quality of the meat. Between 1710 and 1795 the weights of cattle sold at Smithfield more than doubled. By 1795 beeves weighed 800 lb. as compared with 370 lb.; sheep went up from 28 lb. to 80 lb. The improvement in the yield of cereals was no less significant. That of rye or wheat rose from 6-8 bushels to the acre in the Middle Ages to 15-20 bushels; barley yielded up to 36 bushels, oats 32-40 bushels. All this was due to more and better food for the livestock and more manure for the land. More manure raised larger crops: larger crops supported much bigger flocks and herds.

Another change in the countryside accompanied the enclosures. The forests, which since Saxon times had been gradually cleared and converted into manorial lands, had by this process become exhausted. After the Civil War it was realized that the country was running short of the hardwoods needed for maintaining the fleet and for buildings and so forth. An era of tree planting, which continued for two hundred years, was inaugurated by the publication of Evelyn's Sylva in 1678. It was during this period that the English landscape as we know it to-day was created by the judicious laying out of parks, artificial lakes, groups of trees, and woods. All this planting provided an important factor in the maintenance of soil fertility. The roots of the trees and the hedges combed the subsoil for minerals, embodied these in the fallen leaves and other wastes of the trees and shrubs, and so helped to maintain the humus in the soil, as well as the circulation of minerals. The roots also acted as subsoil ploughs and aerating agencies. The cumulative effect of the trees and hedges, which accompanied enclosure, in maintaining soil fertility has passed almost unnoticed. Nevertheless, its importance in humus production and in the availability of minerals must be considerable.

While the policy of enclosure, combined with tree-planting and the creation of the existing English landscape, arrested the fall in soil fertility which was inherent in the open-field system, the freedom of action which followed enclosure afforded full scope to the improver. The restoration of British agriculture owes much to the pioneers among the landlords themselves, particularly to Coke of Holkham (1776-1816), who did much to introduce the Norfolk four-course system--(1) turnips, (2) barley, (3) seeds (clover and rye grass), (4) wheat--into general practice and so to achieve at long last an approach to Nature's law of return. Besides his championship of the Norfolk four-course system, his achievements include the conversion of 2,000,000 acres of waste into well-farmed and productive land, the prevention of famine in England during the Napoleonic Wars, the solution of the rural labour problem in his locality by means of a fertile soil, the demonstration of the principle that money well laid out in land improvement is an excellent investment. He invested half a million sterling in his own property and thereby raised the rent roll of his estate from 2,200 pounds a year to 20,000 pounds. He transformed agriculture in this country by the simple process of first writing his message on the land and then, by means of his famous sheep-shearing meetings, bringing it to the notice of the farming community.

But the replacement of the manorial system by individual farming in fenced fields was attended by some grave disadvantages. The large profits obtained from the sale of wool, for example, while they enriched the few, led to a new conception of agriculture. The profit motive began to rule the farmer; farming ceased to be a way of life and soon became a means of enrichment. Enterprising individuals were afforded considerable scope for using their farms to make money. At the same time, large numbers of less fortunate individuals deprived of their land had either to work for wages or seek a living in the towns.

The various Enclosure Acts, which covered a period of more than 600 years, 1235-1845, therefore led to a new agriculture, the enthronement of the profit motive in the national life, and to the exploitation of coal, iron, and minerals, which is customarily referred to as the Industrial Revolution. This arose from the activities of the tradesmen of the manor, whose calling was destroyed by the Enclosure Acts.

The last of the Enclosure Acts, which finally put an end to the strip system of the open fields, was passed in 1845. About the same time the celebrated Broadbalk wheat plots of the Rothamsted Experimental Station were laid out. This field is divided into permanent parallel strips and cultivated on even more rigid lines than anything to be found in the annals of manorial farming. These plots never enjoy the droppings of livestock: till recently they never had the benefit of the annual rest provided by a fallow. Practically every agricultural experiment station all over the world has copied Rothamsted and adopted the strip system of cultivation. How can such experiments, based on an obsolete method of farming, ever hope to give a safe lead to practice? How can the higher mathematics and the ablest statistician overcome such a fundamental blunder in the original planning of these trials?

The strip system has also been adopted for the allotments round our towns and cities without any provision whatsoever on the part of the authorities to maintain the land in good heart by such obvious and simple expedients as subsoiling, followed by a rest under grass grazed by sheep or cattle, ploughing up, and sheet-composting the vegetable residues. Land under allotments should not be under vegetables for more than five years at a time; this should be followed by a similar period under grass and livestock.

THE INDUSTRIAL REVOLUTION AND SOIL FERTILITY

The released initiative which accompanied the collapse of the manorial system was by no means confined to the restoration of soil fertility and the development of the countryside. The dispossessed craftsmen started all kinds of industries, in which they used as labour-saving devices first water power, then the steam engine, the internal combustion engine, and finally electrical energy. By these agencies the Industrial Revolution, which continues till this day, was set in motion. It has influenced farming in many directions. In the first place, industries have encroached on and seriously reduced the area under cultivation. But by far the most important demand of the Industrial Revolution was the creation of two new hungers--the hunger of a rapidly increasing urban population and the hunger of its machines. Both needed the things raised on the land: both have seriously depleted the reserves of fertility in our soils. Neither of these hungers has been accompanied by the return of the respective wastes to the land. Instead, vast sums of money were spent in completely side-tracking these wastes and preventing their return to the land which so sadly needed them. Much ingenuity was devoted to developing an effective method of removing the human wastes to the rivers and seas. These finally took the shape of our present-day water-borne sewage system. The contents of the dustbins of house and factory first found their way into huge dumps and then into incinerators or into refuse tips sealed by a thin covering of cinders or soil.

At first the additional demands for food and raw materials were met by the restored agriculture and the periodical ploughing up of grass. One of these demands was the vast quantities of corn needed to feed the urban population. The price of wheat was regulated for more than 150 years by a series of Corn Laws, which attempted to hold the balance between the claims of the farmers who produced the grain and those of the consumers and the industrialists who advocated cheap food for their workers, so that they could export their produce at a profit. But as the urban population expanded, the pressure on the fertility of the soil increased until, in 1845, a disastrous harvest and the potato famine compelled the Government in 1846 to yield. The 'rain rained away' the Corn Laws (Prothero).

Deprived of protection, farmers were forced to adopt new methods and to farm intensively. Many developments in farming occurred. Particular attention was paid to drainage: the first drain pipe was made in 1843; two years later the pipes were turned out by a machine. Liebig's famous essay in 1843 drew attention to the importance of manures, While better farm buildings and the preparation of better farmyard manure were adopted, two fatal mistakes were made. Artificial manures like nitrate of soda and superphosphate came into use: imported feeding stuffs for livestock began to take the place of home-grown food. British farming, in adopting these two expedients, because they appeared for the moment to be profitable, laid the foundations of much future trouble But in the use of better implements for the land and the provision of improved transport facilities the countryside was on firmer ground. The result of all these and other developments was a period of great prosperity for farming which lasted till late in the seventies of the last century.

THE GREAT DEPRESSION OF 1879

Then the blow fell. The year 1879, which I remember so vividly, was one of the wettest and coldest on record. The average yield of wheat fell to about fifteen bushels to the acre: large numbers of sheep and cattle were destroyed by disease: the price of wheat fell to an undreamt-of level as the result of large importations from the virgin lands of the New World. The great depression of 1879 not only ruined many farmers, but it dealt the industry a mortal blow. Farmers were compelled to meet a new set of conditions--impossible from the point of view of the maintenance of soil fertility--which have been more or less the rule till the Great War of 1914-18 and the World War which began in 1939 provided a temporary alleviation as far as the sale of produce and satisfactory prices were concerned.

Since 1879 the standard of real farming in this country has steadily fallen. The labour force, particularly the supply of men with experience of and sympathy with livestock, markedly diminished and deteriorated in quality. Rural housing left much to be desired. Drainage was sadly neglected. The small hill farms, which are essential for producing cattle possessing real bone and stamina, fell on evil days. Our flocks of folded sheep, so essential for the upkeep of downland, dwindled. Diseases like foot-and-mouth, tuberculosis, mastitis, and contagious abortion became rampant. Less and less attention was paid to the care of the manure heap and to the maintenance of the humus content of the soil. The NPK mentality (p. 77) replaced the muck mentality of our fathers and grandfathers. Murdered bread, deprived of the essential germ, replaced the real bread of the last century and seriously lowered the efficiency of our rural population. The general well-being of our flocks and herds fell far below that of some of our overseas competitors like the Argentine.

But in this dark picture some rays of light could be detected. The pioneers were busy demonstrating important advances. Among these two are outstanding: (1) the Clifton Park system of farming based on deep-rooting plants in the grass carpet, and (2) the use of the subsoiler for breaking up pans under arable and grass, and so preparing the ground for another great advance--the mechanized organic farming of tomorrow.

THE SECOND WORLD WAR

Such, generally speaking, was the condition of British agriculture in September 1939, when the second world war began and the submarine menace for the second time brought national starvation into the picture. What an opportunity was provided for a Coke of Norfolk for making use of a portion of the resources of a great nation to set British farming on its feet for all time by the simple expedient of restoring and maintaining soil fertility! What an opening was given to the pioneers of human nutrition and the apostles of preventive medicine for feeding the men and women defending the country on the fresh produce of fertile soil and so initiating the greatest food reform in our history! But the potential Cokes of Norfolk had been liquidated or discouraged by many years of death duties, which had destroyed most of our agricultural capital and deprived the countryside of its natural leaders who, in years gone by, had done so much for farming. The apostles of real nutrition and of preventive medicine, such as the panel doctors of Cheshire, were ignored.

A much easier road was taken. The vast stores of fertility, which had accumulated after the long rest under grass, were cashed in and converted into corn crops. The seed so obtained saved the population from starvation, but most of the resulting straw could not be used because of the shortage of labour to handle it and of insufficient cattle to convert it into humus. The grow-more-food policy was, therefore, based on the exhaustion of the soil's capital. It is a perfect example of unbalanced farming. It is therefore certain to sow the seeds of future trouble, which will be duly registered by Mother Earth in the form of malnutrition and disease of crops, livestock, and mankind.

CHAPTER V

INDUSTRIALISM AND THE PROFIT MOTIVE

One of the developments which marks off the modern world is the growth of population. The figures are startling. There were about nine hundred million persons living during the eighteenth century, but over two thousand million at the beginning of the twentieth; in a century and a half world population, therefore, more than doubled. The principal increases took place in Europe.

The first effect of this is obvious--there were many more mouths to feed. Had no other changes accompanied this rise in population, we can guess what might have happened. The density of the peoples in rural Europe might have rivalled that in peasant China, and European agriculture would either have had to evolve methods of intensive cultivation similar to those of the Chinese or the additional population could not have survived.

Fate or their own ingenuity has sent the Western nations along another path. The picture has become quite different from that of the Far East and a very remarkable picture it is. We are so accustomed to it that we scarcely grasp the anomalies which it represents or the dangers into which it is leading us.

THE EXPLOITATION OF VIRGIN SOIL

The new populations did not, as a matter of fact, remain in Europe in their entirety. The Western peoples reached forth and put themselves in possession of vast areas of virgin soil in North America, Australia, New Zealand, and South Africa. Naturally agriculture became extensive, which word means that the cultivator prefers to get a smaller volume of produce per acre off a larger area rather than a great deal from a smaller area more intensively worked. The tracts seized were so enormous that each settler had at his disposal not a tiny piece of ground from which to raise as much produce as possible, but a huge section--running into hundreds of acres for the growing of crops, into thousands for the raising of cattle or sheep. The amount of human effort to be put into each acre became indeed the crucial question--in contrast with Europe the new populations were thin and a thin population means few hands, and few hands can do little manual work. The first significant fact we have to note is the uneven distribution of the enlarged population as between the old and the new countries.

It was in these circumstances that the machine came to the help of agriculture The outcome of the use of machines in farming was revolutionary; this is not always realized. Five men working with the most modern combine (So called because it is a machine combining cutting and threshing. A header is another form of the combine.) can harvest and thresh fifty acres of wheat in the same number of hours as would require 320 persons working with old-fashioned hand tools; two men working with a header can replace 200 working with sickles; other calculations show for certain specified jobs only one-twentieth or even only one-eightieth of the amount of human labour formerly employed. (Howard, Louise E., Labour in Agriculture (Oxford University Press and Royal Institute of International Affairs, 1935), pp. 244-5). If these particular calculations apply exclusively to the easier processes of crop cultivation and reaping, it may also be pointed out that the cream separator and machine milking have effected a dramatic augmentation of the dairy industry by saving human labour.

We have reason to be grateful to those who invented the powerful devices which made possible these results. The food which has fed the great populations of Western civilization has been, in part, machine-produced food; without these machines such populations must have starved. But there is another side to the picture. The ease with which agriculture was mechanized was in itself a temptation and this temptation the Western nations have not been able to withstand. It has seemed so easy to provide enough food with comparatively little human labour, and not only this, but also to supply with raw materials those other machines, industrial in character and situated in manufacturing districts, which have been the invention of an ingenuity even more refined than has gone to the making of the agricultural harvester or combine. From these machines, continuously fed with the wool, cotton, silk, jute, hemp, sisal, rubber, timber, and the oil seeds of the whole world, has flowed a vast stream of industrial articles which have been at the disposal of all and which have given a quite special character to our modern civilization.

The result has been inevitable. The hunger of the urban populations and the hunger of the machines has become inordinate. The land has been sadly overworked to satisfy all these demands which steadily increase as the years pass.

Not even the power of the machine would have been sufficient to feed and supply the immense populations of the nineteenth century, had it not been for the vast natural capital in the shape of the humus stored in the soils or the new continents now opened up. The general exploitation of these soils did not take place until the nineteenth century was well on its way. Then the settlers who had poured westwards in North America, trekked northwards from the coast of South Africa, landed by the boatload in the harbours of New Zealand and Australia, set themselves to exploit this natural wealth with zest: they were eager to follow the covered wagon and to draw the plough over the prairies where once only herds of bison had roamed. Meanwhile in South and Central America, Ceylon, Assam, South India, the Dutch East Indies, and East Africa the plantation system, already known in the eighteenth century in the West Indies, took on a magnitude and an aspect which made it a new phenomenon. From all these sources immense volumes of food and raw materials reached Europe in such abundance that no one stopped to ask whether the stream could continue for ever.

Yet all these processes were almost pure harvesting, a mere interception and conversion of Nature's reserves into another form. It is true the land was tilled after a fashion, cultivated and sown, though in such industries as timber and rubber not even that, the ancient riches of the forest being for many years merely plundered. But whatever cultivation processes were undertaken did not amount to much more than a slight, necessary disturbance of those rich stores of accumulated humus which Nature had for hundreds of years been collecting under the prairie or the forest. So enormous were these reserves that the land bore crop after crop without faltering. In such regions as the great wheat belt of North America fifty years of wealth was available and the farmer knew well how to dig into these riches.

The phrase mining the land is now recognized as a very accurate description of what takes place when the human race flings itself on an area of stored fertility and uses it up without thought of the future. In the mid-nineteenth century this began to take place on an unprecedented scale. For if agriculture was, so to say, the nurse of industry, she was persuaded to learn one salient lesson from her nursling. This was the lesson of the profit motive.

THE PROFIT MOTIVE

Of course, ever since the decay and final collapse of the Feudal System, when service steadily gave place to rents, European agriculture has been working for profit; it was already in Tudor times a feature of the British wool trade which preceded and followed enclosure; the great English agricultural pioneers of the eighteenth century were also perfectly alive to the question of the monetary return for their reforms. Indeed, as soon as any harvest is sold rather than consumed, the question of profit must arise. The problem is one of degree and emphasis. Is profit to be the master? Is it to direct and tyrannize over the aims of the farmer? Is it to distort those aims and make them injure the farmer's way of living? Is it to be pushed even further and to make him forgetful of the conditions laid down for the cultivation of the earth's surface, so that he actually comes to defy those great natural laws which are the very foundation and origin of all that he attempts? If this is so, then the profit principle has outrun its usefulness: it has been dragged from its allotted niche in the world's economy, set on a high altar, and worshipped as a golden calf.

At first sight the profit motive does not seem to have taken modern farming very far. The farmers of the new countries opened up in the nineteenth century did not make vast fortunes. Perhaps in sheep farming and without doubt in the plantation industries large money was at one time made. But on the whole the monetary rewards of the new farming were not impressive. They never bore comparison with the colossal fortunes which nineteenth-century manufacture produced for the factory owner. Unlike the cotton spinner, the North American farmer did not exchange his shack for a huge and luxurious mansion. He remains to this day a dirt farmer, and is proud to call himself so, in close contact with his work and doing it with his own hands. It is, therefore, not easy to grasp that without great personal wealth and with no harmful intentions he was, nevertheless, a true despoiler, and that in so far as the occupation on which he was engaged is the first occupation in the world, while the means which he handled--the soil--is the most sacred of all trusts, he did more harm in his two or three generations than might be thought possible.

The ease with which crops could be grown year after year on new soil tempted the farmer to forget the law about restoring that fertility which he was rapidly using up in his farming operations. The soil responded again and again. Crop after crop of wheat was raised. Labour, as we have seen, was scarce and animals require much knowledge and much attention. As manure did not seem to be required, animals were discarded. Thus the straw could not be rotted down and the normal practice was to burn it off where it stood. In effect this was to repeat that old wasteful practice of the primitive shifting cultivator who renders the tropical forest into ash: in both cases a potentially rich organic matter was reduced to the inert inorganic phase and so deprived of its duty to the soil population. In short, the old mixed husbandry, which had maintained Europe and which not long before the settlers migrated had been so notably improved as really to achieve something approaching a balance of the processes of growth and decay, was never brought across the waters--its principles slipped from the settler's mind: he was unaware of his loss.

THE CONSEQUENCE OF SOIL EXPLOITATION

The result of the exploitation of the soil has been the destruction of soil fertility on a colossal scale. This has taken place in the areas to which we have been referring at different rates over different periods and in response to various factors. The net result of a century's mismanagement in the United States was summed up in 1937 as either the complete or partial destruction of the fertility of over 250,000,000 acres, i.e. 61 per cent of the total area under crops: three-fifths of the original agricultural capital of this great country has been forfeited in less than a century. But New Zealand where a systematic burning of the rich forest to form pasture which in its turn was soon exhausted, parts of Africa where overstocking has ruined much natural grazing, Ceylon where a criminal failure to follow the native practice of terracing for rice has denuded the mountain slopes of their glorious forest humus, would probably show consequences just as startling. Almost everywhere the same dismal story could be related.

When stockbreeding in its turn began to offer strong monetary inducements, especially in Australia and New Zealand in the 1880's and 1890's, another phase set in. Animals were kept in enormous numbers--some sheep runs owned hundreds of thousands of sheep--but scant regard was paid to their nurture; the natural herbage, untouched for centuries, was counted upon and as long as the humus held out such specialized animal husbandry could continue. But when the stores of humus were worked out, trouble began. Disease appeared. Inevitable accidents, especially drought, brought utter disaster: there was colossal mortality. No doubt Nature is prepared for such waste: but man is not. It is a setback for him. The right provision against such emergencies would have been a reserve of fodder in the form of cultivated roots or hay, for drought kills not so much by want of water as by starvation. But as crops were not grown alongside of the animals, there were no such reserves, while the natural remedy of wandering to a new pasture, which might have mitigated the catastrophe for the much smaller numbers of wild animals, was no longer possible. Thousands of sheep or cattle therefore perished: the profit motive had become a boomerang.

As the years have passed, the toll of animal disease has become so severe that Governments feel obliged to compute it statistically and grasp at all remedies. The figures rival in their intrinsic importance the figures of erosion. Actually it is the same bad effect in each case: we are looking at the results of mono-crop farming so called.

Let us recall our examination of the methods of Nature. We had noted among other things that her mechanisms for dispelling and scattering seeds were singularly perfect. Is it not obvious that Nature refuses to grow on any one spot the same crop without other intermixtures? Some aggregation of identical plants may take place: so does some collection of animal life: Nature knows the herd, the swarm--these are her own inventions, but they are set to carry out their lives in a mixed environment of other existences. It is to be noted that in the case of animals their natural range is great, involving change of habitat. It is also, perhaps, worth pondering over that when Nature does breed in one locality a large number of the same animals, these aggregations are particularly liable to be decimated by such diseases as she chooses to introduce; it is as though she herself repented of this principle of aggregation and in her own ruthless way chose for the time being to terminate it. But allowing for these slight modifications, the general economy of Nature is mixed in an extraordinary way. Her sowings and harvestings are intermingled to the last degree, not only spatially, but in succession of time, each plant seizing its indicated opportunity to catch at the nutrient elements in air, earth, or water, and then giving place to another, while some phases of all these growing things and of the animals, birds, and parasites which feed on them are going on together all the time. Thus the prairie, the forest, the moor, the marsh, the river, the lake, the ocean include in their several ways an interweaving of existences which is a dramatic lesson; in their lives, as in their decay and death, beasts and plants are absolutely interlocked. Above all, never does Nature separate the animal and vegetable worlds. This is a mistake she cannot endure, and of all the errors which modern agriculture has committed this abandonment of mixed husbandry has been the most fatal.

It would be to distort the picture unfairly if we were to assume that these mistakes were to be found only in the farming of the new countries. That was by no means the case. The thirst for profit profoundly affected European husbandry also. The yield became everything; quality was sacrificed for quantity. The merest glance at any recent set of agricultural statistics will reveal how wholly this factor of quantity is now insisted upon, indeed is made a boast. Rises in the yield of cereals per acre are everlastingly cited; yields of milk per cow become an obsession. There is, no doubt, virtue in increased volume of produce; it is the aim of agriculture to produce largely, and such increase is useful to mankind. But if the profit and loss account is made to look brilliant merely because capital has been transferred and then regarded as dividend, what business is sound?

THE EASY TRANSFER OF FERTILITY

The using up of fertility is a transfer of past capital and of future possibilities to enrich a dishonest present: it is banditry pure and simple. Moreover, it is a particularly mean form of banditry because it involves the robbing of future generations which are not here to defend themselves.

It is, perhaps, not realized over what distances the transfer of fertility can now take place. This final aspect is an unforeseen consequence of the vast improvement in means of communication. It is not necessary for the modern farmer to cash in his own fertility to make a good income; he has a more subtle means at hand. Before the present world war the telephone farmer, as he was sometimes called, had merely to ring up his agent and the needed quantity of imported foodstuffs, oil-cakes, or whatever it may be, was delivered by lorry the next morning. It was claimed that the dung of his animals was thereby enriched and that whatever fields he condescended to cultivate were thus improved. This is true. But what does it amount to? Merely that the accumulated fertility of those distant regions of the earth which have produced the materials for the oil-cake is being robbed in order to bolster up a worn-out European soil: the same bad process of exhaustion is going on, but at the moment so far away that it can be temporarily ignored. On such a system of imported foodstuffs the whole of the dairy industry of Denmark was built up. The Danish farmer was not carrying on agriculture at all: he was devoting himself to a mere finishing process and what he built up was a conversion industry. It is an astonishing sidelight that before the present war the Danish farmer frequently sold his good butter to the London market and bought the cheaper margarine for his children's use. The pursuit of profit had invaded not only his farming methods but his way of life and had even encroached on the health and well-being of his family.

The transfer of fertility to current account, as it were, has not ceased: soil erosion and the toll of animal disease continue. Two recent writers calculate that erosion is even now proceeding 'at a rate and on a scale unparalleled in history': between 1914 and 1934, they declare, more soil was lost to the world than in all the previous ages of mankind, (Jacks, G. V. and Whyte, R. O., The Rape of the Earth Faber and Faber, London, 1939.) while a host of learned papers are evidence that new diseases of stock are being discovered day after day, baffling both farmer and veterinary surgeon.

The remedy is simple. We must look at our present civilization as a whole and realize once and for all the great principle that the activities of homo sapiens, which have created the machine age in which we are now living, are based on a very insecure basis--the surplus food made available by the plunder of the stores of soil fertility which are not ours but the property of generations yet to come. In a thoughtful article by Mr. H. R. Broadbent recently published in the Contemporary Review (December 1943, pp. 361-4) this aspect of progress is discussed and the conclusion is reached that:

'The whole world has shared, either directly or indirectly, with the United States and British Commonwealth of Nations in the use of the surplus from the eroded lands. It has enabled us to build up our engineering knowledge and technique. Our buildings, engines, and machinery are material evidence of its consumption; but the foundation has been impoverishment of the soil. The food was cheap--the products were cheap because the fertility of the land was neglected. We in England have often been puzzled by the arrival of cheap goods when it was known that high wages were paid to the makers. We had not seen the land which had produced not only the food for those makers, but also the organic material which they processed. . . . We had not seen the gullies torn out from the land by unabsorbed rains and melting snows. We had not seen the dust storms of the wind seeping out the goodness from the soils and carrying it hundreds of miles from its old resting place. When we look on Battersea Power Station or our reclaimed land, the great railroads of the United States or London's Underground, or consider such wonders as the general use of electricity and mechanical transport, the spread of broadcasting and mass-production of clothes, we must also see the devastated lands which have yielded the surplus to make them possible. These things in which we take pride were built on an unbalanced surplus, the unmaintained capital of the soil. No country can continue indefinitely to provide food and material at such a cost. Under extraordinary conditions, as in war, the land must be driven beyond the normal to provide an extravagant surplus. But war is abnormal, and the normality at which we aim is peace which implies stability of foundations. Raymond Gram Swing broadcast that at the rate of soil and water depletion occurring when the 1934 survey was made in fifty years the fertile soil of the United States would be one-quarter of what was present originally, and that in a hundred years at the same rate of depletion the American continent would turn into another Sahara. Perhaps he was thinking of other civilizations buried in the sands; the ruins of ancient towns and villages in the Gobi desert, Palestine, and Mesopotamia. Perhaps he feared the fate of the country north of the Nigerian boundary, where an area as large as the Union of South Africa has become depopulated in the last two hundred years. Perhaps he remembered the malaria-ridden marshes of Greece and Rome which came with the decline of their agricultural population and loss of vigour.'

THE ROAD FARMING HAS TRAVELLED

What is the outcome of our arguments? We started our investigations by considering the operations of Nature and continued them by summarizing human action in relation to those operations. It is our actions, when confronted with forms of natural wealth, which have shaped the modern world in its economic, financial, and political contours. The harvesting, distribution, and use of natural resources is the first condition which determines human societies.

The supplies provided by Nature are the starting point for everything. Primitive societies have to adapt themselves to what supplies lie readily to hand; they sometimes use severe processes of self-correction, e.g. infanticide, in order to do so. But a further stage is usually reached. Nature's supplies are not static; they appear as actual surpluses, and by a bold use of these surpluses societies emerge from the primitive stage. This use later becomes crystallized as the profit motive.

To eliminate this would be impossible. In advanced societies it would be a retrograde step. The profit motive, however far it may have led us astray, is founded on physical realities. It is wiser to go back to those realities, reconsider them, and seek any necessary correction from a better understanding of them.

What are the exact conditions attaching to the creation of the surpluses which Nature accumulates?

In spite of the fact that we speak of her lavishness, Nature is not really luxurious: she works on very small margins. Natural surpluses are made up of minute individual items: the amount contributed by each plant or animal is quite tiny: it is the additive total which impresses us. The further result is that the gross amounts of these surpluses are not disproportionate to their environment: harvests are only a small part of natural existences.

The farmer is apt to disregard these facts. His object is to produce more. It pays him to select a smaller number of plants or animals and make each of these produce more intensively: he counts on the elasticity of Nature. If he kept his harvests to the very small proportions usual in wild existences, his farming would be exceedingly laborious and scarcely worth while: farming improves in proportion to the extra amounts which the cultivator manages to elicit by stimulating rates and intensities of growth. Up to a point he can do this with safety. After that Nature refuses to help him: she simply kills off the over-stimulated existence. Her elasticity is great, but it is not infinite.

Here we may find our principal warning. The pursuit of quantity at all costs is dangerous in farming. Quantity should be aimed at only in strict conformity with natural law, especially must the law of the return of all wastes to the land be faithfully observed. In other words, a firm line needs to be drawn between a legitimate use of natural abundance and exploitation.

Modern opinion is now set against all forms of exploitation. The limitation of money dividends, the disciplining of capital investments have begun. Undertaken originally only from the point of view of economic order, then continued for political and national motives, these measures bear in themselves further possibilities; it would be easy to give them wide moral significance.

In agriculture, which is so much more fundamental than industrial economics, the field is still uncharted. The agricultural expert still holds out the ideal of quantity as the highest aim. Helpless under this leadership, the farmer has first himself been exploited and has then almost automatically become an exploiter. A vicious round has been set up, resistance to which is only just showing itself.

The first pressure has been the pressure of urban demand. This pressure is of long standing and has been very greedy. It has been exercised in strange contradiction to another tendency: while the farmer was asked to produce more, the man-power needed for greater production was enticed away to the cities, there to add to the number of mouths to be fed. The farmer was always being asked to do more with less man-power to do it. This absurdity has not passed unnoticed. Severe criticisms have been enunciated; everyone would agree to any reasonable measures to restore the balance of population. That the balance of physical resources has also been disturbed is only just beginning to be realized. The transference of the wealth of the soil to the towns in the shape of immense supplies of food and raw materials has not been made good by a return of town wastes to the country. This return is a sine qua non and should at all costs include the crude sewage, which is by no means impossible even with modern systems of drainage. If this can be arranged, the existence of cities will cease to be a menace: exploitation will stop, legitimate use will return. Nevertheless, it will always be important to exercise some control over the volume of urban demand, probably by some restrictions on the size of the urban community, which means some restrictions on the launching of new industries or the expansion of old ones. However far off this sort of control may seem at the present time, it must at some future date rank among the preoccupations of the statesman. Otherwise there will never be any protection for the farming world from the incredible demand for quantity.

It has been under the pressure of this insatiable demand that the farmer has himself become an exploiter: in two ways. Having exhausted the possibilities of production from his own fields, he has actually had the temerity to transfer to those fields the stored-up natural wealth, representing centuries of accumulation, lying many thousand miles away. The importation of feeding stuffs, of guanos and manures of all kinds from distant parts of the world to intensify European farming is only robbery on a vast scale. It is not necessary to claim that every national agriculture must be completely self-contained: this would be a great pity. But the tide has been all one way. While from the economic and financial point of view the return flow of manufactured goods is supposed to be a quid pro quo, from the point of view of ultimate realities this type of return is perfectly useless. The draining away of natural fertility from tropical and sub-tropical regions is exceedingly dangerous. It is a point on which the peoples of these regions may later come to put a colossal question to the conscience of the so-called civilized countries: Why has the stored-up wealth of our lands been taken away to distant parts of the world which offer us no means of replacing it?

Even this dangerous expedient has been insufficient. Faced with the demand for higher yields, the farmer has grasped at the most desperate of all methods: he has robbed the future. He has provided the huge output demanded of him, but only at the cost of cashing in the future fertility of the land he cultivates. In this he has been the rather unwilling, but also the rather blind, pupil of an authority he has been taught to respect: the pundits of science have urged him to go forward and have made it a matter of boasting that they have done so. How this has come about will be described in our next chapter.

CHAPTER VI

THE INTRUSION OF SCIENCE

It was Francis Bacon who first observed that any species of plants impoverished the soil of the particular elements which they needed, but not necessarily of those required by other species. This true observation might have put subsequent investigators on the right path had their general knowledge of scientific law been less fragmentary. As it was, many ingenious guesses were made in the course of the seventeenth and eighteenth centuries as to the nurture and growth of plants, some near the truth, some wide of the mark. Confusedly it began to be recognized that plants draw their food from several sources and that water, earth, air, and sunlight all contribute. Priestley's discovery of oxygen towards the end of the eighteenth century opened up a new vista and the principles of plant assimilation soon came to be firmly established, by which is meant the fact that under the influence of light the green leaves absorb carbon-dioxide, break it up, retaining the carbon and emitting the oxygen (hence their purifying effect on the atmosphere)--what is more delicious than the air of the forest, garden, or field?--while without light, i.e. during the night-time, plants reverse the process and emit carbon-dioxide. Though the investigation of the parallel processes of root respiration, i.e. the use made by the roots of the oxygen available from the soil-air or the soil-solution, did not follow until a good deal later, yet the foundations of knowledge about the life of plants were at least thus laid on sound lines.

THE ORIGIN OF ARTIFICIAL MANURES

It was at this juncture that a special direction was given to investigation by Liebig. Liebig is counted the pioneer of agricultural chemistry. His Chemistry in Its Application to Agriculture, contributed to the British Association in 1840, was the starting point of this new science. His inquiries into general organic chemistry were so vast and so illuminating that scientists and farmers alike naturally yielded to the influence of his teaching. His views throughout his life remained those of a chemist and he vigorously combated the so-called humus theory, which attributed the nourishment of plants to the presence of humus. At that time the soil in general and the humus in it were looked on as mere collections of material without organic growth of their own; there was no conception of their living nature and no knowledge whatever of fungous or bacterial rganisms, of which humus is the habitat. Liebig had no difficulty in disproving the role of humus when presented in this faulty way as dead matter almost insoluble in water. He substituted for it a correct appreciation of the chemical and mineral contents of the soil and of the part these constituents play in plant nourishment.

This was a great advance, but it was not noticed at the time that only a fraction of the facts had been dealt with. To a certain extent this narrowness was corrected when Darwin in 1882 published The Formation of Vegetable Mould Through the Action of Worms with Observations of Their Habits, a book founded on prolonged and acute observation of natural life. The effect of this study was to draw attention to the extraordinary cumulative result of a physical turnover of soil particles by natural agents, particularly earthworms. It was a salutary return to the observation of the life of the soil and has the supreme merit of grasping the gearing together of the soil itself and of the creatures who inhabit it. Darwin's book, based as it is on a sort of experimental nature study, established once for all this principle of interlocked life and, from this point of view, remains a landmark in the investigation of the soil.

Meanwhile Pasteur had started the world along the path of appreciating the marvellous existence of the microbial populations traceable throughout the life of the universe, unseen by our eyes but discoverable to the microscope. The effect of his investigations has been immense; enormous new fields of science have been opened up. The application of this knowledge to agriculture was only gradual. Many years slipped by before it was realized that the plants and animals, whose life histories are based ultimately on living protoplasm, have their counterparts in vast families and groups of miscroscopic flora and fauna in the very earth on which we tread.

It thus came about that the chemical aspects of the soil for a long time predominated in the mind of the scientist. The theory had had a good start, it was older and naturally better developed. Moreover, and this is important, Liebig had been a pioneer not only in science, but in practice. From the outset of his experiments he had made every effort to work with the farmer and also by field investigation. The farmer did not object to the help given him in his difficult task. As the demands on him grew to fever pitch, for he was just facing the heavy, cumulative greed of the expanding factories of the world and the hunger of their servants, the workers, he not unnaturally welcomed ideas and suggestions which he was told would enable him to carry out his task in an easy, practical, and clean way without fuss and without that extra labour already so difficult to procure.

Thus artificial fertilizers were born out of the abuse of Liebig's discoveries of the chemical properties of the soil and out of the imperative demands made on the farmer by the invention of machinery. It must be confessed that Liebig himself was somewhat of a sinner on this count. He manufactured artificial manures and though these were oddly enough a failure he maintained his faith, which indeed was questioned by none, that the food of plants could be replenished by the too obvious principle of putting back into the earth the minerals which, as the analysis of the ash of the burnt crops taken off it revealed, were drawn out by the plants.

As long as this principle was held to override every other consideration, no further progress could be made. The effects of the physical properties of the soil were by-passed: its physiological life ignored, even denied, the latter a most fatal error. There was a kind of superb arrogance in the idea that we had only to put the ashes of a few plants in a test tube, analyse them, and scatter back into the soil equivalent quantities of dead minerals. It is true that plants are the supreme, the only, agents capable of converting the inorganic materials of Nature into the organic; that is their great function, their justification, if we like to use that word. But it was expecting altogether too much of the vegetable kingdom that it should work only in this crude, brutal way; as we shall see, the apparent submission of Nature has turned out to be only a great refusal to have so childish a manipulation imposed upon her.

At first all seemed to go well. As economic conditions pressed on the farmer more and more severely, he thankfully grasped at the means of increasing the volume of his production and after the great agricultural depression of 1879 began to use the artificial manures placed on the market for his benefit. These were of two kinds; the nitrogen artificials which supply the current account of plants and which have a marked effect in increasing leafage, and the potash and phosphate artificials which increase the mineral reserves of the soil. The chemical symbol for nitrogen is N; for potassium, K (for Kalium); and for phosphorus, P; and the attitude of mind which sees all virtue in the use of artificials may fairly be dubbed the NPK mentality.

THE ADVENT OF THE LABORATORY HERMIT

Stimulating the growers who began to acquire this mentality, there came to be installed in the strongholds of science a type of investigator whom we are justified in naming the laboratory hermit. The divorce between theory and practice was a new phase which would have been deprecated by Liebig, but the temptation to grow a few isolated plants in pots filled with sand--watered by a solution containing the requisite amount of NPK in a balanced form so that any one constituent did not outdo the others--draw them, measure them, tie them up in muslins, weigh them, burn them, and analyse them proved too great. A quantity of minute investigation was based on these practices, which are only justified as a mere introduction to agricultural investigation. Though the plant may to some extent be grown under these conditions, the soil is another problem. Soil or watered sand in a flower-pot is literally in a straitjacket and it is nonsense to assume that it can carry on its proper life: for one thing the invasion of earthworms or other live creatures is eliminated and many other processes put out of action. That essential co-partnership between the soil and the life of the creatures which inhabit it, to which Darwin's genius had early drawn attention, is wholly forgotten.

To confirm the findings of the flower-pots the small plot trials--in which some fraction of an acre of land is the usual unit--were devised. Great virtues have been attributed to the repetition of such tests over a long period of years and, of late, to the statistical examination of the yields. In this way it was hoped to 'disentangle the effects of various factors and to state a number of probable relationships which can then be investigated in the laboratory by the ordinary single factor method'. (Russell, Sir John, Soil Conditions and Plant Growth (London, 1937), p. 31.)

THE UNSOUNDNESS OF ROTHAMSTED

At this point the manifold weaknesses of the small-plot method of agricultural investigations must be emphasized. The celebrated Broadbalk wheat trials at Rothamsted, the units of which are strips of land some half an acre in size and on whose results the artificial manure industry is largely founded, can be taken as an example. The trials have been repeated for some hundred years, the work has been carried out with extreme care, the fullest records have been kept and preserved, and the final figures have been subjected to the best available statistical analysis.

The main object of these experiments was to determine whether wheat could be grown continuously by means of artificials alone or with no manure, and also to compare the results obtained by chemicals on the one hand and by farmyard manure on the other. The results are considered to prove that under Rothamsted conditions satisfactory yields of wheat can be obtained by means of chemicals only, that no outstanding advantage follows the use of farmyard manure, and further that on the no-manure plot a small but constant yield of grain can be reaped. A subsidiary, but very important, result is also claimed, namely, that the manuring has had no appreciable effect on the quality of the wheat grain.

In spite of all the devotion that has been lavished on these Broadbalk trials, at least four major mistakes have been made in their design and conduct which completely discredit the final results.

In the first place, an error in sampling was made at the very beginning. A small plot cannot possibly represent the subject investigated, namely, the growing of wheat, which obviously can best be studied in this country on a mixed farm. We cannot farm a small strip of wheat land year after year, because it is difficult to cultivate it properly; the area does not come into the usual rotations and is, therefore, not influenced by such things as the temporary ley, by the droppings of livestock, and by periodic dressings of muck. The small plot, therefore, cannot represent any known system of British farming, any of our farms, or even the field in which it occurs. It only represents itself--a small pocket handkerchief of land in charge of a jailor intent on keeping it under strict lock and key for a century; in other words, it has fallen into the clutches of a Gestapo agent. In this sinister sense the Broadbalk trials have indeed been permanent.

In the second place, the continuous cultivation of wheat on a tiny strip of land is certain to create practical difficulties. Such land cannot be kept free from weeds because of the short time available between harvest in August and re-sowing in October. No cleaning crops like roots crop can, therefore, be used. This difficulty duly happened at Rothamsted. The weeds got worse and worse and finally won the battle. Mother Earth rejected the idea underlying the continuous wheat experiment. The original conception of these trials has had to be modified. Fallows have had to be introduced. I last saw these Broadbalk plots about 1918 when this weed difficulty was causing considerable concern. I can truthfully say that never in my long experience have I seen arable land in such a hopeless and filthy condition. A more glaring example of bad farming could scarcely be imagined. I took my leave at the earliest possible moment and decided then and there that my last visit to Rothamsted--the Mecca of the orthodox--had been paid.

In the third place, no steps were taken to isolate the plots from the surrounding areas and to prevent incursions from burrowing animals such as earthworms. It is known from the work of Dreidax (Archiv far Pflanzenbau, 7, 1931, p. 461) and others on the Continent that when the earthworm population is destroyed by artificials, the affected areas are soon invaded by a fresh crop of worms from the neighbouring land. This invasion may take place at the rate of many yards a year. To study the effects of artificials on earthworms Dreidax showed that the experimental area should be at least ten acres and that the fringes of this land should never be taken into account. We know that artificials, sulphate of ammonia in particular, destroy the earthworm population wholesale, (The use of sulphate of ammonia for destroying earthworms on golf putting greens is recommended in Farmers' Bulletin 1569 issued by the United States Department of Agriculture.) but that after the nitrification of this manure has taken place the area is again invaded by more of these animals. A small oblong strip about half an acre in size is, therefore, obviously useless for determining the effect of artificials on the soil population. The unit should be a square at least ten acres in area. This wholesale destruction of the earthworm probably helps to explain the failures in wheat growing which often attend the application of the Rothamsted methods to large areas of land. The lowly earthworm--the great conditioner of the food materials for healthy crops--is murdered and no effective substitute is provided.

In the fourth place, the manurial scheme has never been allowed to impress itself on the variety of wheat grown. The manuring has influenced the soil, but not the plant. The seed used every year has been obtained from the best outside source. The wheat raised on each plot has not been used to sow that plot for the next crop. The plant has had a fresh start every sowing. The Broadbalk experiment is, therefore, not a continuous wheat experiment as regards one of the two most important factors in the trial--the wheat plant itself. How this error crept in is difficult to say. It was most probably due to over-emphasis on the soil factor. Its discovery is largely due to Mr. H. R. Broadbent, who has made a critical study of the published reports on the Broadbalk plots from the beginning with a view to discovering the cause of the discrepancy between the Rothamsted experience and the results of large-scale wheat growing when carried out on the farm. In the discussions which arose Mr. Broadbent asked me where the seed sown every year on these plots came from. As this important fact was not recorded in the various Rothamsted Annual Reports, I asked the authorities to let me know the source of the seed used in the Broadbalk trials and was promptly informed that fresh seed was obtained every year from the best outside source and that the crop from each plot was never used to re-sow that plot. This candid confession invalidates the entire Broadbalk experiment. Had the harvest of each plot been used for resowing, in a very few years an important result would have been obtained. The effect of artificial manures, which we know is cumulative, would soon have begun to influence the stability of the variety itself and cause it to run out. In some period between twenty-five and fifty years the wheat would have ceased to grow and the Broadbalk experiment would have collapsed. This dramatic result, in all probability, would have saved the agriculture of this country and of the world from one of its greatest calamities--the introduction of artificial manures into general practice.

ARTIFICIALS DURING THE TWO WORLD WARS

In 1914, when the first world war broke out, the Broadbalk results were universally accepted as a safe guide for the farmer in the drive for increased food production. But it was the after-effects of this war rather than the four years of the war itself which ushered in a yet more ardent use of artificial fertilizers. The new process of fixing, i.e. combining, nitrogen from the air had been invented and had been extensively employed in the manufacture of explosives. When peace came, some use had to be found for the huge plants set up and it was obvious to turn them over to the manufacture of sulphate of ammonia for the land. This manure soon began to flood the market.

From 1918 onwards the application of artificials was earnestly advocated by all authorities; their use was laid on the farmer almost as a moral duty. The universities had by now been impelled to set up agricultural departments, and finely equipped experiment stations were scattered over the various countries which in their general theory of investigation copied the universities, from which, indeed, they were invariably recruited. All these agencies without exception gave unconscious stress to the NPK mentality and were also hypnotized by the thraldom of fear of the parasite. Two thoroughly unsound and even mischievous principles thus acquired the support of the republics of learning--the universities--and the sanction of science itself. When the present war broke out the stage was set for the next swift advance towards the steep places leading downwards to the sea.

When towards the end of 1939 the menace of the submarine began to imperil our food supplies from overseas, it became crystal clear that the fields of Great Britain would have to grow more and more of our nourishment if starvation were to be avoided. Then for the first and perhaps for the last time artificial manures came into their own: they were available in quantity to stimulate the crops: the Defence Regulations could be invoked to support the grow-more-food policy: the financial resources of a great nation were available to help the farmers to purchase these chemical stimulants and thus indirectly to subsidize the artificial manure industry itself: the staffs of these vested interests were at the disposal of the Ministry of Agriculture: the local War Agricultural Executive Committees soon became salesmen of the contents of the manure bag: the frequent speeches of the Minister of Agriculture invariably contained some exhortation to use more fertilizers. The amalgamation of the vested interests and the official machine which directed war farming became complete. One thing, however, was forgotten. No satisfactory answer to the following question has been provided: What will be the final result of all this on the land itself, on the well-being of crops, livestock, and mankind? Will the grow-more-food policy have solved one problem--the prevention of starvation--by the creation of another--the enthronement of the Old Man of the Sea on farming itself? What sort of account will Mother Earth render for using up the last reserve of soil fertility and for neglecting her great law of return? Who is going to foot the bill?

THE SHORTCOMINGS OF PRESENT-DAY AGRICULTURAL RESEARCH

But the enthronement of the NPK mentality is only one of the blunders for which the experiment stations must be held responsible. The usual sub-division of science into chemical, physical, botanical, and other departments, necessary for the sake of clarity and convenience in teaching, soon began to dominate the outlook and work of these institutions. The problems of agriculture--a vast biological complex--began to be subdivided much in the same way as the teaching of science. Here it was not justified, for the subject dealt with could never be divided, it being beyond the capacity of the plant or animal to sustain its life processes in separate phases: it eats, drinks, breathes, sleeps, digests, moves, sickens, suffers or recovers, and reacts to all its surroundings, friends, and enemies in the course of twenty-four hours, nor can any of its operations be carried on apart from all the others: in fact, agriculture deals with organized entities, and agricultural research is bound to recognize this truth as the starting point of its investigations.

In not doing this, but adopting the artificial divisions of science as at present established, conventional research on a subject like agriculture was bound to involve itself and magnificently has it got itself bogged. An immense amount of work is being done, each tiny portion in a separate compartment; a whole army of investigators has been recruited, a regular profession has been invented. The absurdity of team work has been devised as a remedy for the fragmentation which need never have occurred. This is nonsensical. Agricultural investigation is so difficult that it will always demand a very special combination of qualities which from the nature of the case is rare. A real investigator for such a subject can never be created by the mere accumulation of the second rate.

Nevertheless, the administration claims that agricultural research is now organized, having substituted that dreary precept for the soul-shaking principle of that essential freedom needed by the seeker after truth. The natural universe, which is one, has been halved, quartered, fractionized, and woe betide the investigator who looks at any segment other than his own! Departmentalism is recognized in its worst and last form when councils and super-committees are established--these are the latest excrescences--whose purpose is to prevent so-called overlapping, strictly to hold each man to his allotted narrow path and above all to enable the bureaucrat to dodge his responsibilities. Real organization always involves real responsibility: the official organization of research tries to retain power and avoid responsibility by sheltering behind groups of experts. The result of all this is that a mass of periodicals and learned papers stream forth, of which only a very few contain some small, real contribution.

The final phase has been reached with the letting loose of the fiend of statistics to torment the unhappy investigator. In an evil moment were invented the replicated and randomized plots, by means of which the statisticians can be furnished with all the data needed for their esoteric and fastidious ministrations. The very phrase--statistics and the statistician--should have been a warning. It is, of course, true and known to most persons that average numbers and similar calculations are not perfect; they are subject to various errors. Care is needed in interpreting them and, above all, experience of the actual: where this is available and where common sense is the judge, danger ceases. The deduction would be, in what we are now reviewing, that the agricultural investigator must be well acquainted with practical farming and be prepared to put his conclusions to practical tests over some period of time before he can be certain of what he says. This conclusion is just, and with such a corrective agricultural experiment can live and prosper.

But the exactly opposite conclusion has been drawn. Instead of sending the experimenter into the fields and meadows to question the farmer and the land worker so as to understand how important quality is, and above all to take up a piece of land himself, the new authoritarian doctrine demands that he shut himself up in a study with a treatise on mathematics and correct his first results statistically. The matter has been pursued with zest and carried to all extremes; it is popularly rumoured that only one highly qualified individual is now able to interpret the mathematical principles on which are based the abstruse mass of calculations to which even the simplest experiments give rise.

But the proof of the pudding is in the eating thereof. Can the statistician give any practical help when the use of small plots gets into difficulties? In one case I personally investigated about 1936 the answer is: Most emphatically, no. This occurred at the Woburn Experiment Station, a branch of Rothamsted. During the summer I was invited by the Vice-President of the Rothamsted Trust, the late Professor H. E. Armstrong, F.R.S., to help him to discover why one of the sets of permanent manurial experiments at Woburn had come to an end. After a long treatment with artificials the soils on the greensand had gone on strike: the cereals refused to grow. Why? I have a vivid recollection of this visit. We were first given a learned lecture on the past history of the plots with tables and curves galore by the Officer-in-Charge. We then visited the field, for which the professor said I was certain to need a spade. We saw the plots which had given up the struggle. No crop was to be seen, only a copious growth of the common mare's tail (Equisetum arvense). I then inquired whether a really good crop could be seen on similar land. We were shown a fine crop of lucerne nearby which had been manured with copious dressings of pig muck. The cause of the going on strike of the Woburn plots was now clear and the cure was obvious, but before explaining all this to the Officer-in-Charge I inquired what had been done by the Rothamsted staff to elucidate this trouble. It appeared that all the data and all the information available had been laid before the Director and his staff, including the statisticians, but without result. Neither the official hierarchy nor the higher mathematics had any explanation or advice to offer. I thereupon explained the cause and pointed to the cure of the mischief. Constant applications of chemicals to this sandy soil had so stimulated the soil organisms that the humus, including the humic cement of the compound soil particles, had been used up. This had led to pan formation and to the cutting off of the air supply to the subsoil. All this was obvious by the establishment of a weed flora mostly made up of a species of Equisetum. My diagnosis would be confirmed by an examination of the soil profile which would disclose a sand pan some six to nine inches below the surface and the development of the characteristic root system of this weed of poorly aerated soils. This injurious soil condition could be removed by a good dressing of muck followed by a crop of lucerne. A soil profile was then exposed and there was the pan and the root system exactly as I foreshadowed. It was merely a case of reading one's practice in the plant. The establishment of the mare's tail on a high-lying sand could only be possible by poor soil aeration due, in all probability, to the formation of a subsoil pan so common in sandy soils. Farmyard manure, plus a deep-rooting crop and earthworms, would prevent pan formation, hence the good crop of lucerne. Long practical experience and many years spent in root studies had instantly suggested the cause of the Woburn trouble. Many years' observation and first-hand experience of the lucerne crop enabled me to suggest a cure for the pan formation. How could statistics and the higher mathematics be a substitute for the faculty of reading one's practice in the plant? How could this faculty be developed except by a wide experience of research methods and of practical farming?

Can statistics or the statistician help in unravelling the nature of quality--that factor which matters most in crop production, in animal husbandry, and in human nutrition? We cannot measure or weigh quality and express the result in numbers which the statistician can use. But our livestock instantly appreciate quality and show by their preference, their better health, their improved condition and breeding performance how important it is. The animal, therefore, is a better judge of one of the factors that matters most in farming than the mathematician. But on this important point--the verdict of the animal--the records of our experiment stations are silent. At these institutions crops are weighed on metal or wooden balances so that figures--the food of the statistician--can be provided. But if many of these experimental crops, particularly those raised with chemical manures, are tested in the stomachs of our livestock--the real balance of the farmer--they will be found wanting.

The invasion of statistics into agricultural research has been an incursion into a diseased field. Let us sum up this chapter by judging this result of our modern civilization by its works. This surely is not unfair. Of some fifteen committees set up in Great Britain under the Agricultural Research Council just before the present war no less than twelve were allocated to investigation of the diseases of animals and plants. Of the enormous mass of scientific literature published on agricultural problems some third part is concerned with the onset, history, description, or attempted remedies for some form of sickness or disability in crops or livestock. This merely reflects the facts. Old diseases are spreading and new diseases are appearing. Eelworm devours our potato crop, foot-and-mouth disease infects our cattle, grass sickness kills our horses, fungi, viruses, and insect parasites invade our fruit and our vegetables: every vine in France is smothered in green and blue copper compounds to keep the mildews at bay. Comparatively new crops like the sugar beet are now retreating before the onset of the eelworm. New scientific organizations and their satellite companies for dealing with the increasing manufacture and sale of insecticides and fungicides are being created. The farmers are being urged to subscribe to panels of veterinarians to control the growing toll of disease among their livestock.

Even a Beveridge health plan is now being advocated by the National Veterinary Association, who also favour 'the establishment of State breeding farms to facilitate the improvement of average stock by direct mating and by controlled artificial insemination' (Daily Express, 16th March 1944). The practice of artificial insemination for livestock can only be described as a monstrous innovation which can only end in life-erosion. Already many of the men who know most about animal breeding are in revolt; they are convinced this unnatural practice is bound to end in sterility and disaster.

The catalogue could be multiplied ad infinitum. The toll of disease is extraordinary and a matter of the utmost anxiety to the farmer. The public is not sufficiently aware of this unsatisfactory state of affairs. If these are the results of agricultural science, they are not encouraging and certainly are not impressive. They are undoubtedly a phenomenon of the last forty or fifty years and appear alongside of the modern use of artificial manures. This book asks the question whether we have here not things merely juxtaposed, but actual cause and result.

It is even more legitimate to ask what agricultural science would be at. It is a severe question, but one which imposes itself as a matter of public conscience, whether agricultural research in adopting the esoteric attitude in putting itself above the public and above the farmer whom it professes to serve, in taking refuge in the abstruse heaven of the higher mathematics, has not subconsciously been trying to cover up what must be regarded as a period of ineptitude and of the most colossal failure. Authority has abandoned the task of illuminating the laws of Nature, has forfeited the position of the friendly judge, scarcely now ventures even to adopt the tone of the earnest advocate: it has sunk to the inferior and petty work of photographing the corpse--a truly menial and depressing task.

PART II DISEASE IN PRESENT-DAY FARMING AND GARDENING

A simple method of estimating the success of any method of farming is to observe how it is affected by disease. If the soil is found to escape the two common ailments--erosion and the formation of alkali salts--which afflict cultivated land; if the crops raised are found to resist the various insect, fungous, and virus diseases; if the livestock breed normally and remain in good fettle; if the people who feed on such crops and livestock are vigorous, prolific, and more or less free from the many diseases from which mankind suffers; then the method of farming adopted is supported by the one unanswerable argument--success. It has passed the stiffest examination it can be made to undergo--it has yielded results comparable with those to be seen in the wayside hedges of this country of Great Britain. These strips closely resemble in their agriculture the primeval forest.

In our roadside hedges hardly a trace of the common diseases of the soil are to be seen; the wildings come into flower regularly every spring and early summer; there is no running out of the variety and no necessity to supply new and improved strains of seeds; one generation follows another century after century; the vegetable life of the hedgerow is to all intents and purposes eternal; there is very little plant disease. A similar story can be told of the birds and other animal life. The wayside hedge is, therefore, an example of successful soil management for all to see and study. It has stood the test of time.

In striking contrast to the picture of general health and well-being which has just been lightly sketched is the spectacle of widespread disease which has resulted from many of the methods of farming, and particularly the modern methods, which have so far been devised. Disease of one kind or another is the rule; robust health is the exception.

Let us, therefore, examine in some detail the generous dividends in the form of trouble with which Mother Earth has rewarded our methods of agriculture. The examples chosen have been largely taken from my own personal experience. They are arranged in their natural order starting with the diseases of the soil, then going on to the maladies of crops and livestock, and ending with the afflictions of homo sapiens himself.

CHAPTER VII

SOME DISEASES OF THE SOIL

SOIL EROSION

Perhaps the most widespread and the most important disease of the soil at the present time is soil erosion, a phase of infertility to which great attention is now being paid.

Soil erosion in the very mild form of denudation has been in operation since the beginning of time. It is one of the normal operations of Nature going on everywhere. The minute mineral particles which result from the decay of rocks find their way sooner or later to the ocean, but many may linger on the way, often for centuries, in the form of one of the constituents of fertile fields. This phenomenon can be observed in any river valley. The fringes of the catchment area are frequently uncultivated hills, through the thin soils of which the underlying rocks protrude. These are constantly weathered and in the process yield a continuous supply of minute mineral fragments in all stages of decomposition.

The slow rotting of exposed rock surfaces is only one of the forms of decay: the surfaces not exposed are also subject to change. The covering of soil is no protection to these underlying strata, but rather the reverse, because the soil water, containing carbon dioxide in solution, is constantly disintegrating the parent rock, first producing subsoil and then actual soil. In this way the constant supply of minerals--like phosphates, potash, and the trace elements needed by crops and livestock--are automatically transferred to the surface soil from the great mineral reservoir of the primary and secondary rocks. Simultaneously with these disintegration processes the normal decay of animal and vegetable remains on the surface of the soil is giving rise to the formation of humus.

All these processes combine to start up denudation. The fine soil particles of mineral origin, often mixed with fragments of humus, are gradually removed by rain, wind, snow, or ice to lower regions. Ultimately the rich valley lands are reached, where the accumulations may be many feet in thickness. One of the main duties of the streams and rivers which drain the valley is to transport these soil particles into the sea, where fresh land can be laid down. The process looked at as a whole is nothing more than Nature's method of the rotation, not of the crop, but of the soil itself. When the time comes for the new land to be enclosed and brought into cultivation, agriculture is born again. Such operations are well seen in England in Holbeach Marsh and similar areas round the Wash. From the time of the Romans to the present day new areas of fertile soil, which now fetch 100 pounds an acre or even more, have been recreated from the uplands by the Welland, the Nene, and the Ouse. All this fertile land, perhaps the most valuable in England, is the result of two of the most widespread processes in Nature--weathering and denudation.

But Nature has devised a most effective brake. The nature of this retarding mechanism is of supreme importance, because it provides the key to the solution of the problem of soil erosion. Nature's control of the rate of denudation is to create the compound soil particle. The fragments of mineral matter derived from the weathering of rocks are combined by means of the specks of glue-like organic matter supplied mostly by the dead bodies of the soil bacteria which live on humus; as in a building made of bricks, some suitable cementing material is needed before the fragments of mineral matter in the soil can cohere. There must be sufficient of this cement of the right type always ready, so that when the mineral fragments come together a piece of glue is there at hand of a size corresponding to the minute areas of contact. This involves the constant production of large quantities of this bacterial cement. Provided, however, that we keep up the bacterial population of the land in any catchment area, the supplies of glue for making new compound soil particles and for repairing the old ones will be assured.

It will be seen from this how fundamentally important is the role of humus. It is the humus which feeds the bacterial life, which, so to say, glues the soil together and makes it effective. If the supply of glue is allowed to fall into arrears, the compound soil particles will soon lie about in ruins and so provide more raw material for speeding up the process of denudation. The mineral particles are thereby released and ready for their final journey by water to the sea to form new soil, or by wind to form a new dust bowl and so begin a new desert.

It is when the tempo of denudation is vastly accelerated by human agencies that a perfectly harmless natural process becomes transformed into a definite disease of the soil. The condition known as soil erosion--a man-made disease--is then established. It is, however, always preceded by infertility: the inefficient, overworked, dying soil is at once removed by the operations of Nature and hustled towards the ocean, so that new land can be created and the rugged individualists--the bandits of agriculture--whose cursed thirst for profit is at the root of the mischief can be given a second chance. Nature is anxious to make a new and better start and naturally has no patience with the inefficient. Perhaps when the time comes for a new essay in farming, mankind will have learnt the great lesson--how to subordinate the profit motive to the sacred duty of handing over unimpaired to the next generation the heritage of a fertile soil. Soil erosion is nothing less than the outward and visible sign of the complete failure of a farming policy. The root causes of this failure are to be found in ourselves.

The damage already done by soil erosion all over the world, looked at in the mass, is very great and is rapidly increasing. The regional contributions to this destruction, however, vary widely. In some areas like north-western Europe, where most of the agricultural land is under a permanent or temporary cover crop (in the shape of grass or leys) and there is still a large area of woodland and forest, soil erosion is a minor factor in agriculture. In other regions like parts of North America, Africa, Australia, New Zealand, and the countries bordering the Mediterranean, where extensive deforestation has been practiced and where almost uninterrupted cultivation has been the rule, large tracts of land once fertile have been almost completely destroyed.

The United States of America is perhaps the only country where anything in the nature of an accurate estimate of the damage done by erosion has been made. Theodore Roosevelt first warned the country as to its national importance. Then came the Great War with its high prices, which encouraged the wasteful exploitation of soil fertility on an unprecedented scale. A period of financial depression, a series of droughts and dust storms, emphasized the urgency of the salvage of agriculture. During Franklin Roosevelt's presidency soil conservation became a political and social problem of the first importance. In 1937 the condition and needs of the agricultural land of the United States of America were appraised. No less than 253,000,000 acres, or 61 per cent of the total area under crops, had either been completely or partly destroyed or had lost most of its fertility. Only 161,000,000 acres, or 39 per cent of the cultivated area, could be safely farmed by present methods. In less than a century the United States has, therefore, lost nearly three-fifths of its agricultural capital. If the whole of the potential resources of the country could be utilized and the best possible practices introduced everywhere, about 447,466,000 acres could be brought into use--an area actually greater than the present crop land of 415,334,931 acres. The position, therefore, is not hopeless. It will, however, be very difficult, very expensive, and very time-consuming to restore the vast areas of eroded land even if money is no object and large amounts of manure are used and green-manure crops are ploughed under.

Such, in this great country, are the results of misuse of the land. The causes of this misuse include lack of individual knowledge of soil fertility on the part of the pioneers and their descendants; the traditional attitude which regarded the land as a source of profit; defects in farming systems, in tenancy, and finance--most mortgages contain no provisions for the maintenance of fertility; instability of agricultural production as carried out by millions of individuals, prices, and income, in contrast to industrial production carried on by a few large corporations. The need for maintaining a correct relation between industrial and agricultural production, so that both can develop in full swing on the basis of abundance, has only recently been understood. The country was so vast, its agricultural resources were so immense, that the profit seekers could operate undisturbed until soil fertility--the country's capital--began to vanish at an alarming rate.

The resources of the Government are now being called up to put the land in order. The magnitude of the effort, the mobilization of all available knowledge, the practical steps that are being taken to save what is left of the soil of the country and to help Nature to repair the damage already done are graphically set out in Soils and Men, the Year Book of the United States Department of Agriculture of 1938. This is perhaps the best local account of soil erosion which has yet appeared. The progress that has been made in recent years can be followed in Soil Conservation, a monthly periodical issued by the Soil Conservation Service of the United States Department of Agriculture, Washington, D.C.

The rapid exploitation of Africa was soon followed by soil erosion. In South Africa, a pastoral country, some of the best grazing areas are already semi-desert. The Orange Free State in 1879 was covered with rich grass, interspersed with reedy pools, where now only useless gullies are found. Towards the end of the nineteenth century, it began to be realized all over South Africa that serious over-stocking was taking place. In 1928 the Drought Investigation Commission reported that soil erosion was extending rapidly over many parts of the Union and that the eroded material was silting up reservoirs and rivers and causing a marked decrease in the underground water supplies. The cause of erosion was considered to be the reduction of vegetal cover brought about by incorrect veldt management--the concentration of stock in kraals, overstocking, and indiscriminate burning to obtain fresh autumn or winter grazing. In Basutoland, a normally well watered country, soil erosion is now the most immediately pressing administrative problem. The pressure of population has brought large areas under the plough and has intensified over-stocking on the remaining pasture. In Kenya the soil erosion problem has become serious during the last ten years, both in the native reserves and in the European areas. In the former, wealth depends on the possession of large flocks and herds; barter is carried on in terms of livestock; the bride price is almost universally paid in anima's s; numbers rather than quality are the rule. The natural consequence is overstocking, over-grazing, and the destruction of the natural covering of the soil. Soil erosion is the inevitable result. In the European areas, erosion is caused by long and continuous over-cropping without the adoption of measures to prevent the loss of soil and to maintain the humus content. Locusts have of late been responsible for greatly accelerated erosion; examples are to be seen when the combined effect of locusts and goats has resulted in the loss of a foot of surface soil in a single rainy season.

The countries bordering the Mediterranean provide striking examples of soil erosion, accompanied by the formation of deserts which are considered to be due to one main cause--the slow and continuous deforestation of the last 3,000 years. Originally well wooded, no forests are to be found in the Mediterranean region proper. Most of the original soil has been washed away by the sudden winter torrents. In North Africa the fertile cornfields which existed in Roman times are now desert. Ferrari in his book on woods and pastures refers to the changes in the soil and climate of Persia after its numerous and majestic parks were destroyed; the soil was transformed into sand; the climate became arid and suffocating; springs first decreased and then disappeared. Similar changes took place in Egypt when the forests were devastated; a decrease in rainfall and in soil fertility was accompanied by loss of uniformity in the climate. Palestine was once covered with valuable forests and fertile pastures and possessed a cool and moderate climate; to-day its mountains are denuded, its rivers are almost dry, and crop production is reduced to a minimum.

The above examples indicate the wide extent of soil erosion, the very serious damage that is being done, and the fundamental cause of the trouble--misuse of the land, resulting in the destruction of the compound soil particles. In dealing with the remedies which have been suggested and which are now being tried out, it is essential to envisage the real nature of the problem. It is nothing less than the repair of Nature's drainage system--the river--and of Nature's method of providing the countryside with a regular water supply. The catchment area of the river is the natural unit in erosion control. In devising this control we must restore the efficiency of the catchment area as a drain and also as a natural storage of water. Once this is accomplished, we shall hear very little about soil erosion.

Japan provides perhaps the best example of the control of soil erosion in a country with torrential rains, highly erodible soils, and a topography which renders the retention of the soil on steep slopes very difficult. Here erosion has been effectively held in check by methods adopted regardless of cost, for the reason that the alternative to their execution would be national disaster. The great danger from soil erosion in Japan is the deposition of soil debris from the steep mountain slopes on the rice fields below. The texture of the rice soils must be maintained so that the fields will hold water and allow of the minimum of through drainage. If such areas become covered with a deep layer of permeable soil, brought down by erosion from the hillsides, they would no longer hold water and rice cultivation--the mainstay of Japan's food supply--would be out of the question. For this reason the country has spent as much as ten times the capital value of eroding land on soil conservation work, mainly as an insurance for saving the valuable rice lands below. Thus, in 1925 the Tokyo Forestry Board spent 453 yen (45 pounds) per acre in anti-erosion measures on a forest area valued at 40 yen per acre in order to save rice fields lower down valued at 240 to 300 yen per acre.

The dangers from erosion have been recognized in Japan for centuries and an exemplary technique has been developed for preventing them. It is now a definite part of national policy to maintain the upper regions of each catchment area under forest as the most economical and effective method of controlling flood waters and insuring the production of rice in the valleys. For many years erosion control measures have formed an important item in the national budget.

According to Lowdermilk (Oriental Engineer, March 1927), erosion control in Japan is like a game of chess. The forest engineer, after studying his eroding valley, makes his first move, locating and building one or more check dams. He waits to see what Nature's response is. This determines the next move which may be another dam or two, an increase in the former dam, or the construction of retaining side walls. After another pause for observation a further move is made and so on until erosion is checkmated. The operation of natural forces, such as sedimentation and re-vegetation, are guided and used to the best advantage to keep down costs and to obtain practical results. No more is attempted than Nature has already done in the region. By 1929 nearly 2,000,000 hectares of protection forests were used in erosion control. These forest areas do more than control erosion. They help the soil to absorb and retain large volumes of rain water and to release it slowly to the rivers and springs.

China, on the other hand, presents a very striking example of the evils which result from the inability of the administration to deal with the whole of a great drainage area as one unit. On the slopes of the upper reaches of the Yellow River extensive soil erosion is constantly going on. Every year the river transports over 2,000,000,000 tons of soil, sufficient to raise an area of 400 square miles by five feet. This is provided by the easily erodible loess soils of the upper reaches of the catchment area. Some of the mud is deposited in the river bed lower down, so that the embankments which contain the stream have constantly to be raised. Periodically the great river wins in this unequal contest and destructive inundations result. The labour expended on the embankments is lost, because the nature of the erosion problem as a whole has not been grasped, and the area drained by the Yellow River has not been studied and dealt with as a single organism. The difficulty now is the over-popuration of the upper reaches of the catchment area, which prevents afforestation and laying down to grass. Had the Chinese maintained effective control of the upper reaches--the real cause of the trouble--the erosion problem in all probability would have been solved long ago at a lesser cost in labour than that which has been devoted to the embankment of the river. China, unfortunately, does not stand alone in this matter. A number of other rivers, like the Mississippi, are suffering from overwork, followed by periodical floods as the result of the growth of soil erosion in the upper reaches.

Although the damage done by uncontrolled erosion all over the world is very great and the case for action needs no argument, nevertheless there is one factor on the credit side which has been overlooked. A considerable amount of new soil is being constantly produced by natural weathering agencies from the subsoil and the parent rock. This, when suitably conserved, will soon re-create large stretches of valuable land. One of the best regions for the study of this question is the black cotton soil of Central India which overlies the basalt. Here, although erosion is continuous, the soil does not often disappear altogether, for the reason that, as the upper layers are removed by rain, fresh soil is re-formed from below. The large amount of earth so produced is well seen in the Gwalior State, where the late ruler employed an irrigation officer, lent by the Government of India, to construct a number of embankments, each furnished with spillways, across many of the valleys, which had suffered so badly by uncontrolled rain wash in the past that they appeared to have no soil at all, the scrub vegetation just managing to survive in the crevices of the bare rock. How great is the annual formation of new soil, even in such unpromising circumstances, must be seen to be believed. In a few years the construction of embankments was followed by stretches of fertile land which soon carried fine crops of wheat. A brief illustrated account of the work done by the late Maharaja of Gwalior would be of great value at the moment for introducing a much needed note of optimism in the consideration of this soil erosion problem. Things are not quite so hopeless as they are often made to appear.

Why is the forest such an effective agent in the prevention of soil erosion? The forest does two things: (1) the trees and undergrowth break up the rainfall into fine spray and the litter on the ground further protects the soil from the impact of the descending water stream; (2) the residues of the trees and animal life met with in all woodlands are converted into humus, which is then absorbed by the soil underneath, increasing its porosity and water-holding power; the soil cover and the soil humus together prevent erosion and at the same time store large volumes of water. These factors--soil protection, soil porosity, and water retention--conferred by the living forest cover, provide the key to the solution of the soil erosion problem. All other purely mechanical remedies, such as terracing and drainage, are secondary matters, although, of course, important in their proper place.

The secret of soil conservation is thus seen to lie, first, in maintaining the soil cover in good condition to ensure that the rainfall is received on the surface in a proper manner with no disturbance of the soil below, and second, in conserving ample supplies of humus so that by means of the compound soil particles the water, when it has descended, is adequately absorbed and stored: as well might we expect a living creature to survive without its protective skin as to suppose that the earth can live without her proper covering. The forest has been cited as the pre-eminent example of these protective devices, for the leafage is thick and the ground litter abundant. In the absence of forest some form of grass cover is the natural protective agent which will for centuries often maintain the soil in good heart. Indeed, this device of the grass cover is far more efficient than might be supposed possible. The accumulations of humus under a grass carpet are often immense; they are, indeed, so extraordinary that they can be described as veritable mines of fertility. This is proved by the fact that an agriculture based on their spoliation can, in favourable circumstances, continue for many years before it fades out. But fade out it must if the humus is never restored. Williams (Timiriasev Academy, Moscow) regarded grass as the basis of all agricultural land utilization and the soil's chief weapon against the plundering instincts of humanity. He advanced the hypothesis that the decay of past civilizations was due to the wholesale ploughing up of grass necessitated by the increasing demands of civilization. His views are exerting a marked influence on soil conservation policy in the U.S.S.R. and indeed apply to many other countries.

Grass is a valuable factor in the correct design and construction of surface drains. Whenever possible these should be wide, very shallow, and completely grassed over. The run-off then drains away as a thin sheet of clear water, leaving all the soil particles behind. The grass is thereby automatically manured and yields abundant fodder. This simple device was put into practice at the Shahjahanpur Sugar Experiment Station in India. The earth service roads and paths were excavated so that the level was a few inches below that of the cultivated area. They were than grassed over, becoming very effective drains in the rainy season, carrying off the excess rainfall as clear water without any loss of soil.

If we regard erosion as the natural consequence of improper methods of agriculture and the catchment area of the river as the natural unit for the application of soil conservation methods, the various remedies available fall into their proper place. The upper reaches of each river system must be afforested; cover crops, including grass and leys, must be used to protect the arable surface whenever possible; the humus content of the soil must be increased and the crumb structure restored, so that each field can drink in its own rainfall; over-stocking and over-grazing must be prevented; simple mechanical methods for conserving the soil and regulating the run-off, like terracing, contour cultivation and contour drains, must be utilized. There is, of course, no single anti-erosion device which can be universally adopted. The problem must, in the nature of things, be a local one. Nevertheless, certain guiding principles exist which apply everywhere. First and foremost is the restoration and maintenance of the crumb structure of the soil, so that each acre of the catchment area can do its duty by absorbing its share of the rainfall.

THE FORMATION OF ALKALI LAND

When the land is continuously deprived of oxygen, the plant is soon unable to make use of the nourishment it contains: it becomes a dead instrument, from which no crop can draw anything. If left to itself, this condition of infertility is permanent.

In many parts of the tropics and sub-tropics agriculture is interfered with and even brought to an end because of the injury inflicted on the soil by accumulations of soluble salts composed of various mixtures of the sulphate, chloride, and carbonate of sodium. Such areas are known as alkali lands. When the alkali phase is still in the mild or incipient stage, crop production becomes difficult and care has to be taken to prevent matters from getting worse. When the condition is fully established, the soil dies; crop production is then out of the question. Alkali lands are common in Central Asia, India, Persia, Iraq, Egypt, North Africa, and the United States.

At one period it was supposed that alkali salts were the natural consequences of a light rainfall, insufficient to wash out of the land the salts which always form in it by progressive weathering of the rock powder, of which all soils largely consist. Hence alkali lands were considered to be a natural feature of arid tracts such as parts of north-west India, Iraq, and northern Africa, where the rainfall is very small. Such ideas of the origin and occurrence of alkali lands do not correspond with the facts and are quite misleading. The rainfall of the Province of Oudh in India, for example, where large stretches of alkali lands naturally occur, is certainly adequate to dissolve the comparatively small quantities of soluble salts found in these infertile areas, if their removal were a question of sufficient water only. In North Bihar the average rainfall in the submontane tracts where large alkali patches are common is about fifty to sixty inches a year. Arid conditions, therefore, are not essential for the production of alkali soils; heavy rainfall does not always remove them.

What is a necessary condition is impermeability. In India, whenever the land loses its porosity by the constant surface irrigation of stiff soils with a tendency to impermeability, by the accumulation of stagnant subsoil water, or through some interference with surface drainage, alkali salts sooner or later appear. Almost any agency, even over-cultivation or over-stimulation by means of artificial manures, both of which oxidize the organic matter and slowly destroy the crumb structure, will produce alkali land. In the neighbourhood of Pusa in North Bihar old roads and the sites of bamboo clumps and of certain trees, such as the tamarind (Tamarindus indica L.) and the pipul (Ficus religiosa L.), always give rise to alkali patches when they are brought into cultivation. The densely packed soil of such areas invariably shows the bluish-green markings which are associated with the activities of those soil organisms existing in badly aerated soils without a supply of free oxygen. A few inches below the alkali patches which occur on the stiff, loess soils of the Quetta valley, similar bluish-green and brown markings always occur. In the alkali zone in North Bihar wells have always to be left open to the air, otherwise the water is contaminated by sulphuretted hydrogen, thereby indicating a well-marked, reductive phase in the deeper layers. In a subsoil drainage experiment on the black soils of the Nira valley in Bombay, where perennial irrigation was followed by the formation of alkali land, Mann and Tamhane found that the salt water which ran out of these drains soon smelt strongly of sulphuretted hydrogen and a white deposit of sulphur was formed at the mouth of each drain, proving how strong were the reducing actions in this soil. Here the reductive phase in alkali formation was unconsciously demonstrated in an area where alkali salts were unknown until the land was waterlogged by over-irrigation and the oxygen supply of the soil was restricted.

The view that the origin of alkali land is bound up with defective soil aeration is supported by the recent work on the origin of salt water lakes in Siberia. In Lake Szira-Kul between Bateni and the mountain range of Kizill Kaya, Ossendowski observed in the black ooze taken from the bottom of the lake and in the water a certain distance from the surface an immense network of colonies of sulphur bacilli, which gave off large quantities of sulphuretted hydrogen and so destroyed practically all the fish in this lake. The great water basins in central Asia are being metamorphosed in a similar way into useless reservoirs of salt water, smelling strongly of hydrogen sulphide. In the limans near Odessa and in portions of the Black Sea a similar process is taking place. The fish, sensing the change, are slowly leaving this sea as the layers of water, poisoned by sulphuretted hydrogen, are gradually rising towards the surface. The death of the lakes scattered over the immense plains of Asia and the destruction of the impermeable soils of this continent from alkali salt formation are both due to the same primary cause--intense oxygen starvation. In the instances just mentioned this oxygen starvation occurs naturally; in other cases it follows perennial irrigation.

Every possible gradation in alkali land is met with. Minute quantities of alkali salts in the soil have no injurious effect on crops or on the soil organisms. It is only when the proportion increases beyond a certain limit that they first interfere with growth and finally prevent it altogether. Leguminous crops are particularly sensitive to alkali, especially when this contains carbonate of soda. The action of alkali salts on the plant is a physical one and depends on the osmotic pressure of solutions, which increases with the amount of the dissolved substance. For water to pass readily from the soil into the roots of plants, the osmotic pressure of the cells of the root must be considerably greater than that of the soil solution outside. When the soil solution becomes stronger than that of the cells, water passes backwards from the roots to the soil and the crops dry up. This state of affairs inevitably occurs when the soil becomes charged with alkali salts beyond a certain point. The crops are then unable to take up water and death results. The roots behave like a plump strawberry when placed in a strong solution of sugar; like the strawberry they shrink in size because they have lost water to the stronger solution outside. Too much salt in the water, therefore, makes irrigation water useless and destroys the canal as a commercial proposition.

The reaction of the crop to the first stages in alkali production is interesting. For twenty years at Pusa and eight years in the Quetta valley I had to farm land, some of which hovered, as it were, on the verge of alkali. The first indication of the condition is a darkening of the foliage and the slowing down of growth. Attention to soil aeration, to the supply of organic matter, and to the use of deep-rooting crops like lucerne and the pigeon pea, which break up the subsoil, soon set matters right. Disregard of Nature's danger signals, however, leads to trouble--a definite alkali patch is formed. When cotton is grown under canal irrigation on the alluvial soils of the Punjab, the reaction of the plant to incipient alkali is first shown by the failure to set seed, on account of the fact that the anther, the most sensitive portion of the flower, fails to function and to liberate its pollen. The cotton plant naturally finds it difficult to obtain from mild alkali soil all the water it needs--this shortage is instantly reflected in the breakdown of the floral mechanism.

Is the alkali condition confined to the tropics and sub-tropics? May it not, under certain circumstances, occur in temperate regions such as north-western Europe? Is it a factor in the sandy soils of Wareham in Dorsetshire recently investigated by Professor Neilson-Jones and Dr. Rayner? It is impossible at the moment to answer these questions till the soil studies of the future consider the biological activities in relation to the physical and chemical factors as well as to the season. They may not have reached the grade of decay known as alkali land, but they are starved of oxygen, all the conditions needed for the establishment of the anaerobic and semi-anaerobic state being present. This is made clear by the readiness with which they respond to any improvement in surface and subsoil drainage, as well as to sub-soiling. Soil conditions must be looked at as a living and changing system and not merely as something static and stable. The soils of the north temperate zone, for example, often suffer from poor soil aeration. Moreover, many of the soil profiles exhibit the blue and red markings so common under alkali patches, as well as bands of humus which must have been originally formed near the surface, then carried in solution and afterwards precipitated. The soil organisms, which reduce compounds containing sulphur to sulphuretted hydrogen, are known to exist in these soils. All facts point to the necessity for further work so as to provide a clear answer to the above mentioned questions, while from the practical point of view there is an immense field for improvement, especially by means of sub-soiling, over many areas which are now allowed to continue in a very unsatisfactory state. The problem of soil aeration is by no means, therefore, confined to the tropics, and it behoves the pioneers of farming in the temperate countries to turn an immediate attention to the various fairly simple devices by which very great, and above all, permanent improvements could be effected.

The stages in the development of the alkali condition are somewhat as follows. The first condition is an impermeable soil. Such soils--the usar plains of northern India for example--occur naturally where the climatic condition favour those biological and physical factors which destroy the soil structure by disintegrating the compound particles into their ultimate units. These latter are so extremely minute and so uniform in size that they form with water a mixture possessing some of the properties of colloids which, when dry, pack into a hard, dry mass, practically impenetrable to water and very difficult to break up. Such soils are very old. They have always been impermeable and have never come into cultivation.

In addition to the alkali tracts which occur naturally, a number are in course of formation as the result of errors in soil management, the chief of which are as follows:

(a) The excessive use of irrigation water: this gradually destroys the binding power of the organic cementing matter which glues the soil particles together, and further displaces the soil air. Anaerobic changes, indicated by blue and brownish markings, first occur in the lower layers and finally lead to the death of the soil. It is this slow destruction of the living soil that must be prevented if the existing schemes of perennial irrigation are to survive. The process is taking place before our eyes to-day in the Canal Colonies of India, where irrigation is loosely controlled.

(b) Over-cultivation without due attention to the replenishment of humus: in those continental areas like the Indo-Gangetic plain, where the risk of alkali is greatest, the normal soils contain only a small reserve of humus, because the biological processes which consume organic matter are very intense at certain seasons, due to sudden changes from low to very high temperatures and from intensely dry weather to periods of moist, tropical conditions. Accumulations of organic matter such as occur in temperate zones are impossible. There is, therefore, a very small margin of safety. The slightest errors in soil management will not only destroy the small reserve of humus in the soil, but also the organic cement on which the compound soil particles and the crumb structure depend. The result is impermeability, the first stage in the formation of alkali salts. The inhabitants of these areas through the centuries have followed methods of cultivation which are perfectly adapted to preserve the safety margin, but there is a tendency on the part of the shortsighted Western scientist to teach them so-called techniques of stimulating crop production which are highly dangerous from this point of view. One suggestion that is constantly being put forward is the introduction into the Indo-Gangetic plain of artificial manures like sulphate of ammonia. This would soon lead to catastrophe.

(c) The use of artificial manures, particularly sulphate of ammonia: even where there is a large safety margin, i.e. a large reserve of humus, such dressings do untold harm. The presence of additional combined nitrogen in an easily assimilable form stimulates the growth of fungi and other organisms which, in the search for the organic matter needed for energy and for building up microbial tissue, use up first the reserve of soil humus and then the more resistant organic matter which cements the soil particles. This glue is not affected by the processes going on in a normally cultivated soil, but it cannot withstand the same processes when stimulated by dressings of artificial manures.

Alkali land, therefore, starts with a soil in which the oxygen supply is permanently cut off. Matters then go from bad to worse very rapidly. All the oxidation factors which are essential for maintaining a healthy soil cease. A new soil flora--composed of anaerobic organisms which obtain their oxygen from the sub-stratum--is established. A reduction phase ensues. The easiest source of oxygen--the nitrates--is soon exhausted. The organic matter then undergoes anaerobic fermentation. Sulphuretted hydrogen is produced as the soil dies, just as in the lakes of central Asia. The final result of the chemical changes that take place is the accumulation of the soluble salts of alkali land--the sulphate, chloride, and carbonate of sodium. When these salts are present in injurious amounts, they appear on the surface in the form of snow-white and brownish-black incrustations. The former (white alkali) consists largely of the sulphate and chloride of sodium, and the latter (the dreaded black alkali) contains sodium carbonate in addition and owes its dark color to the fact that this salt is able to dissolve the organic matter in the soil and produce physical conditions which render drainage impossible. According to Hilgard, sodium carbonate is formed from the sulphate and chloride in the presence of carbon dioxide and water. The action is reversed in the presence of oxygen. Subsequent investigations have modified this view and have shown that the formation of sodium carbonate in soil takes place in stages. The appearance of this salt always marks the end of the chapter. The soil is dead. Reclamation then becomes difficult on account of the physical conditions set up by these alkali salts and the dissolved organic matter.

The occurrence of alkali land, as would be expected from its origin, is extremely irregular. When ordinary alluvial soils like those of the Punjab and Sind are brought under perennial irrigation, small patches of alkali first appear where the soil is heavy; on stiffer areas the patches are large and tend to run together. On open, permeable stretches, on the other hand, there is no alkali. In tracts like the western districts of the United Provinces, where irrigation has been the rule for a long period, zones of well aerated land carrying fine irrigated crops occur alongside the barren alkali tracts. Iraq also furnishes interesting examples of the connection between alkali and poor soil aeration. Intensive cultivation under irrigation is only met with in that country where the soils are permeable and the natural drainage is good. Where the drainage and aeration are poor the alkali condition at once becomes acute. There are, of course, a number of irrigation schemes, such as the staircase cultivation of the Hunzas in northwest India and of Peru, where the land has been continually watered from time immemorial without any development of alkali salts. In Italy and Switzerland perennial irrigation has been practiced for long periods without harm to the soil. In all such cases, however, careful attention has been paid to drainage and aeration and to the maintenance of humus; the soil processes have been confined by Nature or by man to the oxidative phase; the cement of the compound particles has been protected by keeping up a sufficiency of organic matter.

The theory of the reclamation of alkali land is very simple. All that is needed, after treating the soil with sufficient gypsum (which transforms the sodium clays into calcium clays), is to wash out the soluble salts, to add organic matter, and then to farm the land properly. Such reclaimed soils are then exceedingly fertile and remain so. If sufficient water is available, it is sometimes possible to reclaim alkali soils by washing only. I once confirmed this. The berm of a raised water channel at the Quetta Experiment Station was faced with rather heavy soil from an alkali patch. The constant passage of the irrigation water down the water channel soon removed the alkali salts. This soil then produced some of the heaviest crops of grass I have ever seen in the tropics. When, however, the attempt is made to reclaim alkali areas on a field scale by flooding and draining, difficulties at once arise unless steps are taken first to replace all the sodium in the soil complex by calcium and then to prevent the further formation of sodium clays. Even when these reclamation methods succeed, the cost is always considerable; it soon becomes prohibitive; the game is not worth the candle. The removal of alkali salts is only the first step; large quantities of organic matter are then needed; adequate soil aeration must be provided; the greatest care must be taken to preserve these reclaimed soils and to see that no reversion to the alkali condition occurs. It is exceedingly easy under canal irrigation to create alkali salts on certain areas. It is exceedingly difficult to reverse the process and to transform alkali land back again into a fertile soil.

An interesting development in the reclamation of alkali soils has recently taken place at the Coleyana Estate in the Montgomery District of the Punjab. The method adopted is a first-rate pointer to the right way of solving this or any other agricultural problem. It consists in a clever diagnosis of natural processes and an ingenious adaptation of them to attain the wished-for end. Nature is made, as it were, to retrace certain steps so as to re-establish more desirable soil conditions; she is asked to undo her own work. On the Coleyana Estate Colonel Sir Edward Hearle Cole, C.B., C.M.G., first removes the accumulations of alkali salts from the surface, then ploughs them up and plants dhup grass (Cynodon dactylon, Pers.) which is grazed as heavily as possible by sheep and cattle for some eighteen months to two years. The turf is then killed by a turnover plough followed by a fallow during the hot season (May and June). The land is then prepared for a green-manure crop, followed by a couple of wheat crops in succession, and then put into lucerne or cotton. The great thing in this reclamation work is to scrape off all alkali salts as they appear, remove them from the land, and use the minimum irrigation water for the establishment and maintenance of the crop of grass. The underground stems and roots of the grass then aerate the heavy soil: the sheet-composting of the turf and the droppings of the livestock create the large quantities of humus needed to get this heavy land into condition for wheat, cotton, and lucerne. Sir Edward is now making a point of never leaving such reclaimed land uncovered so as to make the fullest use of the energy of sunlight in creating vegetable matter, which ultimately gets converted into humus. He also takes advantage of deep-rooting plants such as chicory, lucerne, and arhar (Cajanus indicus, Spreng.) for breaking up the subsoil and is a firm believer in the principles set out in The Clifton Park System of Farming. In this way, areas once ruined by alkali salts are now producing crops of wheat up to 1,600 lb. to the acre. This is, perhaps, the simplest and easiest method of reclaiming alkali soils that has yet been devised. It makes the crop itself do most of the work. (Indian Farming, I, 1940, p. 280.)

A further development of the Coleyana method of reclaiming alkali land suggests itself. When the grass crop is ploughed up, it might be worth while to sub-soil the land to a depth of fifteen to eighteen inches four feet apart, using a caterpillar tractor and a Ransomes sub-soiler. This would shatter the deeper soil layers, provide abundant aeration, and prepare the land for the succeeding crops.

Nature has provided, in the shape of alkali salts, a very effective censorship for all schemes of perennial irrigation. The conquest of the desert by the canal by no means depends on the mere provision of water and arrangements for the periodical flooding of the surface. This is only one of the factors of the problem. The water must be used in such a manner and the soil management must be such that the fertility of the soil is maintained intact. There is obviously no point in creating at vast expense a Canal Colony and producing crops for a generation or two, followed by a permanent desert of alkali land. Such an achievement merely provides another example of agricultural banditry. It must always be remembered that the ancient irrigators never developed any efficient method of perennial irrigation, but were content with the basin system, a device by which irrigation and soil aeration can be combined. (The land is embanked; watered once; when dry enough it is cultivated and sown. In this way water can be provided without any interference with soil aeration.) In his studies on irrigation and drainage, King concludes an interesting discussion of this question in the following words which deserve the fullest consideration on the part of the irrigation authorities all over the world:

'It is a noteworthy fact that the excessive development of alkalis in India, as well as in Egypt and California, is the result of irrigation practices modern in their origin and modes and instituted by people lacking in the traditions of the ancient irrigators, who had worked these same lands thousands of years before. The alkali lands of to-day, in their intense form, are of modern origin, due to practices which are evidently inadmissible, and which in all probability were known to be so by the people whom our modern civilization has supplanted.'

These words should be studied by all who are concerned with the extension of irrigation schemes. The unwise pursuance of such schemes with a view to the immediate production of easily grown crops without the lasting maintenance of fertility can only end in the regular suffocation of precious tracts of the earth's surface.

CHAPTER VIII

THE DISEASES OF CROPS

Disease in crops manifests itself in a great variety of ways. Troubles due to parasitic fungi and insects are by far the most common. Many of these troubles have occurred from time to time all through the ages and are by no means confined to modern farming. In recent years attention has been paid to a number of other diseases, such as those due to eelworm, to virus, and to the loss of the power of the plant to reproduce itself. The varieties of our cultivated crops nowadays show a great tendency to run out and to become unremunerative. This weakness, which might be described as varietal-erosion or species-erosion, has to be countered by the creation of a constant stream of new varieties obtained either by plant breeding methods or by importation from other localities. Besides the many cases of running out, failure to set seed is also due to unfavourable soil conditions, the removal of which puts an end to the trouble.

The great attention now devoted to disease will be clear from the operations of the Empire Cotton Growing Corporation, a State-aided body incorporated by Royal Charter on 1st November 1921 for the development of cotton production in the Empire. Among the many activities of this Corporation is the publication of the Empire Cotton Growing Review, a feature of which are the notes on current literature. During the six years before the war, 1934-9 these abstracts of papers on cotton research cover 964 pages of print, of which no less than 223, i.e. 23 per cent, deal with the diseases of cotton. These figures roughly correspond with the way the money contributed all over the world for the production, improvement, and testing of new cottons is spent. Some quarter of the technical staff engaged in this work devote their whole time to the study of the diseases of the cotton plant.

That something must be wrong with the production of cotton throughout the Empire and indeed throughout the world is suggested by a comparison between the above alarming figures and my own experience at the Institute of Plant Industry at Indore in Central India, at which research centre cotton was the principal crop. Between the years 1924 and 1931 cotton disease at Indore was to all intents and purposes negligible. I can recall only one case of wilt on some half dozen plants in a waterlogged corner of a field in a year of exceptionally high rainfall. The cotton plant in India always impressed me as a robust grower capable of standing up well to adverse soil and weather conditions. The examples of disease I came across in my many tours always seemed to be a consequence of bad farming, all capable of elimination by improved methods of agriculture.

As my adventures in research began in the West Indies in 1899 as a mycologist, I have naturally followed very closely the subsequent work on the various diseases of crops and have always been interested in the many outbreaks of these troubles which have occurred all over the world. Since 1905 I have been in a position to grow crops myself and thus have been able to test the validity of the principles on which the conventional methods of disease control are based. Perhaps the simplest way of dealing with these experiences, observations, and resections will be crop by crop.

In perusing the following pages one thing will strike the reader forcibly. I have found it impossible to separate the disease from the growing crop. The study of plant diseases for their own sake is proving an increasingly intricate game, to which modern scientists have devoted many wasted hours. Such studies would be amusing if they were not tragic, for no disease in plant, animal, or man can properly be viewed unless it is looked on as an interference with, or, to speak more plainly, as the distortion or negation of that positive aspect of the growing organism which we call health.

Consequently it is essential to conceive of the plant, for instance, as a living and growing thing, flourishing in certain conditions but wilting or perishing in other conditions; in any discussion of plant disease the right and the wrong methods of growing the crop are not simply the background to the argument, they are its very substance: to investigate plant diseases without a first-hand experience of growing the plant is to play Hamlet without the Prince of Denmark.

SUGAR-CANE

While in the West Indies (1899-1902) I devoted much attention to the fungous diseases of sugar-cane, but only succeeded in writing a few routine papers on the subject, all of no particular importance. Some twenty-five years later at Indore I grew a number of excellent crops of cane and converted them into crude sugar, both of which proceedings won the approval of the local Indian population. This experience brought out one of the weaknesses in present-day research. Between the years 1899 and 1902 I could only write technical papers on the diseases of the cane, as I had no opportunity of growing the crop or of manufacturing it into sugar. I was then in the straitjacket stage of my career. It was not till a quarter of a century later in another continent that the chance came to grow sugar-cane, to the study of whose diseases I had devoted so much attention. It is safe to say that, had these periods been reversed, my papers on the fungous diseases of cane would have made very different reading.

The methods adopted in growing sugar-cane on the black cotton soils at Indore were a copy of those devised by the late Mr. George Clarke, C.I.E., at the Shahjahanpur Experiment Station and described in detail in Chapter XIV of An Agricultural Testament. The crop is planted in shallow trenches, two feet wide, four feet from centre to centre, the soil from each trench being removed to a depth of six inches and piled on the two-foot space left between each two trenches, the whole making a series of ridges as illustrated in Fig. 1.

FIG. 1. Trench System at Indore

As soon as the trenches are made in November, they are dug to a further depth of six inches and compost is thoroughly mixed with the soil of the floor of the trenches, which are then watered, cultivated when dry enough, and allowed to remain till planting time in February. In this way the soil in which the cuttings are to be planted is given time to prepare the food materials needed when growth begins. After planting and watering, the surface soil is lightly cultivated to prevent drying out. Afterwards four or five waterings are given, each followed by surface cultivation, which carry on the crop during the hot season till the break of the rains in June, when no further irrigation is needed.

When the young canes are about two feet high and are tillering vigorously, the trenches are gradually filled in, beginning about the middle of May and completing the operation by the middle of June, when the earthing up of the canes commences. This operation is completed about the middle of July (Fig. 2).

FIG. 2. Earthing up Sugar-cane at Shahjahanpur, 10th July 1919

One of the consequences of filling in the trenches and of earthing up canes grown in fertile soil is the copious development of fungi, which are plainly visible as threads of white mycelium all through the soil of the ridges and particularly round the active roots. I saw these for the first time at the Manjri sugar-cane farm near Poona about 1920 and the same thing was frequently observed at Shahjahanpur. No one suspected then that this fungous development could be explained by the fact that the sugar-cane is a mycorrhiza former and that we were observing the first stage of an important symbiosis between the fungi living on the humus in the soil and the sap of the sugar-cane. The provision of all the factors needed for this association--humus, soil aeration, moisture, and a constant supply of fresh, active roots from the lower nodes of the canes as the earthing-up process proceeds--explains why such good results have always followed the Shahjahanpur method of growing the cane and why the crops are so healthy. When grown on the flat under monsoon conditions, want of soil aeration and want of a constant supply of fresh roots would always be limiting factors in the full establishment of the mycorrhizal association

As at Shahjahanpur, the operation of earthing up the canes served four purposes: (1) the succession of new roots arising from the lower nodes, thoroughly combed the highly aerated and fertile soil of the ridges; (2) the conditions suitable for the constant development of the mycorrhizal association were provided; (3) the standing power of the canes during the rains was vastly improved, and (4) the excessive development of colloids in the surface soil was prevented. When this earthing up is omitted, a heavy crop of cane is liable to be levelled by the monsoon gales; crops which fall down during the rains do not ripen properly, do not give either the maximum yield of sugar or the much-prized, light-coloured product.

The operation of earthing up left deep drains between the rows of cane. It was essential, as at Shahjahanpur, to arrange that these drains were suitably connected with the ditches which carried off the surplus monsoon rainfall, so that no waterlogging of the area under cane occurred.

At Indore the Shahjahanpur results were repeated. The intensive cultivation of a suitable variety (POJ 213 and Coimbatore 213), proper soil aeration, good surface drainage, and an adequate supply of organic matter produced very fine yields of cane, free from fungous and virus diseases and exceptionally good samples of crude sugar (gur). The yields were not quite up to the Shahjahanpur standard, because it takes some years to work up the black soils to the highest pitch of fertility on account of the physical character of these heavy soils, but I am convinced that this was only a matter of perseverance. Unfortunately the time of retirement came before I could achieve the full results, but the remarkable yields obtained in the first three years left no doubt in my mind of the final result. There is no question but that the way to grow cane is the Shahjahanpur method, which should be adopted all over the world, particularly for raising the plant material.

No fungous or virus diseases were observed at Indore. The growth of cane and the ripening process were almost ideal. But not quite. It was noticed that the length of the nodes formed under irrigation during the hot season was rather short. Some factor seemed to be retarding growth during this period. At the time I put this down to the fact that the land under cane had only just been brought under irrigation and that insufficient time had been allowed to get these fields into that high state of fertility so essential when ordinary, rain-fed, black soils are converted into well-irrigated land. As a rule this takes five years in Central India. This retardation in growth during the hot season was accompanied by a very mild attack of the moth borer (Diatrea saccharalis), which lays its eggs in clusters on the under-side of the leaves and is followed by the destruction of the young shoots invaded by the caterpillars. Only a few shoots were destroyed; nothing was done to check the moth. As soon, however, as the rains broke, this pest disappeared of its own accord and no further damage occurred. Obviously some factor was operating during the hot season which altered the sap and lowered the resistance of the cane. I suspected at the time that the soil was not sufficiently fertile and did not contain sufficient humus for supplying the young growing cane with all the water it needed, and that this very minor trouble would disappear when the irrigated area was got into really good fettle. This is obviously a matter calling for detailed investigation.

At Indore the only manure used in raising the cane crop was compost. At Shahjahanpur the canes were grown on green-manure supplemented by a light dressing of cattle manure applied to the land before the green crop was sown. The only examples of organic manuring in commercial cane growing I have been able to discover are in Mauritius, where livestock are kept solely for their manure, which is used to break down cane trash into a rough form of compost. Thus at the Benares estate the residues of 140 cattle are converted into 1,500 tons of compost at a total cost of 6s. 6d. a ton. At Mon Tresor estate 5,000 tons of compost were made at a similar cost from the residues of 300 cattle and 500 sheep and goats. Further details of this organic manuring in Mauritius are to be found in a paper by G. C. Dymond reprinted in the News-Letter on Compost, No. 7, October 1943, p. 44.

In recent years another type of sugar-cane disease--virus--has assumed considerable importance. If virus is nothing more than a condition caused by imperfectly synthesized protein, aggravated by the use of artificials like sulphate of ammonia in place of humus, it would follow that a drastic alteration in manuring might remove the virus condition and restore health. In Natal this has been accomplished. Mr. G. C. Dymond found that when Uba canes, attacked by streak disease (a virus trouble), were manured with compost and the process was repeated for a year or two, the crop threw off the disease and grew normally. The restoration of health was accompanied by the establishment of the mycorrhizal association, which was absent in the cases of streak disease examined.

Dymond's discovery that freshly prepared compost not only restores virus-infected canes to health, but also re-establishes the mycorrhizal association, is of great importance in the future studies of cane diseases. The first step in such inquiries should be to examine the mycorrhizal status of the affected plants and then to restore it by growing cuttings of the diseased plants in heavily composted soil. In all probability the disease will disappear. Steps should then be taken to apply this knowledge on a field scale and then to see whether such crops can be infected by disease. If, as is most probable, no infection takes place, then the cause of the trouble--bad farming--has been established, as well as the remedy--freshly prepared humus.

The next step will be to see how many of the fungous, insect, and virus diseases of the cane survive the Shahjahanpur methods of cane growing. This at least is certain--the number will be few, perhaps none. In this way sugar-cane pests can be used as agricultural censors; their prevention will tune up practice; mycologists and entomologists will then become active and useful agents in development.

Intimately bound up with the prevention of cane diseases is the maintenance of the variety. As has already been pointed out (p. 23), the kinds of cane grown in the East have lasted for many centuries; on the modern sugar plantations a constant stream of new kinds has to be created. The prevention of this deterioration would seem to be bound up with the prevention of disease--the maintenance without any sign of progressive deterioration in the synthesis of protein. This is accomplished in the indigenous sugar industry of India by the use of cattle manure and the restriction of the cuttings used in planting to the joint immediately below the cane tops. These are buried at harvest time and carefully kept till the new field is planted. Commercial sugar estates might copy this well-tried practice and so save the time and money expended in testing a constant stream of new canes.

COFFEE

In the course of my travels I have seen something of coffee cultivation --in the West Indies, in various parts of India, and in the coffee-growing areas of Africa. I also visited in 1908 and again in 1938 the eroded areas in the centre of Ceylon which were devoted to coffee till the well-known rust fungus--Hemileia vastatrix--destroyed the plantations wholesale and caused them to be planted in tea. In all this two things impressed me very much: (1) the marked response of the coffee bush to forest soils rich in humus, and (2) the poor growth seen on areas suffering from erosion. On reconsidering in 1938 the original accounts of the great fungous epidemic in Ceylon some sixty years before, it appeared to me that the loss of the fertile top soil by erosion and the inadequate provision of fresh supplies of humus were ample reasons why this coffee disease had put an end to the industry. This surmise was strengthened by the establishment of the fact that coffee is a mycorrhiza former. This point is referred to in the following extract from my report dated 18th April 1938 on a visit to the tea estates in India and Ceylon:

'In view of the results obtained on the coffee estates in Kenya and Tanganyika with compost, it was expected that mycorrhiza would be found in this crop. Unfortunately my tour did not include any coffee estates where the Indore Process had been adopted. Three samples of surface roots, however, were collected.

'The first was taken from stray coffee plants growing on the roadside on unmanured land under grass at Dholai (Cachar, Assam). As was expected, Dr. Rayner found no trace of mycorrhiza in these root samples.

'Two more promising samples were collected at Talliar (High Range, Travancore), one from a nursery, the other from established coffee. In both cases the soil contained forest humus and in both Dr. Rayner found endotrophic fungous infection of the same type as that described in tea, but confined to the older roots and sporadic in distribution.

'The evidence, although incomplete and fragmentary, nevertheless points to mycorrhiza being as important a factor in coffee cultivation as it is proving in tea.'

These observations were confirmed and amplified by the examination of material sent from Costa Rica by Senor Don Mariano Montealegre. There is no doubt that coffee, like tea and cacao, is a mycorrhiza former.

The fact that coffee is a mycorrhiza former is of considerable significance in the future cultivation of this crop. The humus in the soil and the sap of the plant are in intimate contact by means of this natural mechanism. Obviously, therefore, if coffee of the highest quality is to be produced and if the plants are to withstand disease, the first condition of success in coffee cultivation is the provision of properly made humus.

This naturally involves some form of mixed farming so that an ample supply of urine and dung is available on the spot. Pigs, buffaloes, and cattle will probably be the best agents for this purpose. The day, therefore, may not be far distant when the coffee estates will be partly devoted to livestock, which will automatically cancel out the present expenditure on artificial manures and insecticides, and do much to raise the yield per acre and also improve the quality--a matter of supreme importance in this crop.

One illuminating consequence of the devastating epidemic of coffee leaf disease in Ceylon impressed me during my tours in the island in 1908 and thirty years later in 1938. The many planters I met not only had not forgotten this visitation, but were still labouring under the thraldom of fear of the parasite. When I suggested that fungous and insect diseases are the direct consequence of mistakes in crop production and should, therefore, be regarded as friendly professors of agriculture provided by Nature free of charge for our instruction, I found myself up against a solid armour-plate of fear. Disease, like erosion, were things which had to be studied by specialists and then tackled by direct action.

Under these unpromising conditions I did not pursue the subject and go on to suggest that Hemileia Vastatrix would prove most useful in another way. This disease of the coffee plant might well be used not only to teach us how to grow coffee properly, but also in reference to another crop--the tea plant. A few coffee plants, established here and there among the tea, would tell us whether the soils of Ceylon had been sufficiently restored to fertility by the anti-erosion methods undertaken, by the planting of adequate shade, and above all by the practice of systematically converting all vegetable and animal residues into humus. They could do this without any soil analyses or other laboratory tests by simply withstanding the onset of the leaf disease or by succumbing to it; where the disease appeared, we should know that the soil still lacked fertility; when it was absent, we should be able to be satisfied with the measures taken.

Such a device would be very simple. It would be efficient because it would be using Nature's own agencies in testing conditions. Why should we not make use of so excellent and so inexpensive a method? The Ceylon tea planter should look on coffee and the diseases it carries as one of his best, his most willing, and his most reliable assistants.

TEA

Although a number of insect and fungous diseases have been reported on the tea plant, nevertheless the total damage done by these pests is not excessive Nothing like the coffee leaf disease of Ceylon, which in a few years destroyed the plantations wholesale, has been reported in the case of tea. Indeed in Ceylon, as has already been stated, tea replaced coffee on the partially eroded soils, a fact which suggests that the tea bush is exceptionally hardy and robust. This view is confirmed by the behaviour of this species under cultivation. The plants are constantly plucked and so deprived of those portions of their foliage richest in food materials; every few years the bushes are heavily pruned, after which they have to re-create themselves; in China a tea plantation lasts a century or more. Only a very vigorous bush could endure such treatment for so long.

It would follow from all these considerations that the struggle between the host and the parasite might easily result in the victory of the former, if the tea plant were given a little assistance. It might then be easy to reduce the damage done by pests to something quite insignificant.

Can the tea plant itself throw any light on this question of natural resistance to disease? Has the tea bush anything to say about the assistance it needs to vanquish the various insect and fungous pests always ready to attack it? If so, its representations must be carefully studied and if possible implemented. The plant or the animal will answer most queries about its needs if the questions are properly posed. The wise farmer, planter, or gardener always deals with such responses with sympathy and respect.

The tea plant has very recently delivered a most emphatic message on the cause of disease and its prevention which is certain to interest many readers in no way connected with the tea industry. The story I have to tell began in 1933 when I interested myself in the career of Dr. C. R. Harler (who had just been retrenched when the Tocklai Research Station, maintained by the Indian Tea Association, was reorganized in that year). I consoled him for his temporary loss of employment by assuring him: (1) that retrenchment, as in his case, often falls on the best men; (2) that he could do much more for the tea industry as an independent worker with adequate scope than as a member of the obsolete organization he had just left; and (3) that a promising line of future work lay in the systematic conversion into humus of the waste products of the tea estates. He agreed. Then Providence intervened on his behalf, on behalf of the tea plant and of the tea industry. Dr. Harler was offered and accepted (August 1933) the post of Scientific Officer to the Kanan Devan Hills Produce Company in the High Range, Travancore, the property of Messrs. James Finlay & Co. Ltd., who direct the largest group of tea gardens in the world. On taking up his duties at Nullatanni near Munnar, Dr. Harler proceeded to apply the Indore Process on an estate scale. No difficulties were met with in working the method; ample supplies of vegetable wastes and cattle manure were available; the local labour took to the work and soon the General Manager of the Company, as well as the Estate Managers, became enthusiastic. It was now possible to pose the following question to the tea plant: What do you need to throw off disease and to do your best as regards the yield and quality of tea?

The second half of this question was soon answered on the Kanan Devan tea gardens, the first half had to wait till some years later. The pioneering work at Nullatanni, which was completed towards the end of 1934, was followed by the adoption of the Indore Process on the rest of the gardens--some forty in number. Each garden made from its available vegetable and animal wastes all the manure the tea needed; no artificials were necessary; yield and quality notably improved. But the tea plant in these gardens could say nothing about its requirements to ward off disease for the simple reason that with one small exception--the minor root trouble referred to below--there was practically no disease to resist in these well managed properties. All that properly made compost could do was to increase the yield and improve the quality of the tea above the high standard already reached.

When the news of Dr. Harler's successful estate-scale trial at Nullatanni reached me in September 1934, it occurred to me that it might be worth while bringing the possibilities of the Indore Process to the notice of the rest of the tea industry, which is arranged in large groups controlled by a small London directorate principally recruited from the industry itself. As I had no contacts with these bodies it was necessary to make one--preferably with some pioneer likely to be interested. I soon found the man--Mr. James Insch, one of the then Managing Directors of Messrs. Walter Duncan & Company. A small-scale trial of the Indore Process was completed on fifty-three estates of this group in Sylhet, Cachar, the Assam Valley, the Dooars, Terai, and the Darjeeling District. By the beginning of 1935 some 2,000 tons of compost in all were made and distributed. Five years later the quantity on the Duncan group had passed the 150,000 tons a year mark. But again the tea plant on these widely distributed properties did not answer the question: What do you need to throw off disease? The reason for this was that, as on the High Range of Travancore, the amount of disease on these estates was insufficient for such a question to be posed and answered. On these properties all the Indore Process could do was. to raise the yield and improve the quality still further.

The results already referred to and the publicity they received came to the notice of many other groups of tea estates in India, Ceylon, and Africa The methods of composting which had proved so successful on the Finlay and Duncan estates were tried at many new centres. It was in the course of these widely dispersed trials that the tea plant informed us what it needed to keep insect and fungous pests in check and why it wanted this assistance.

In a few cases during this third series of trials both insect and fungous diseases did occur to an extent which reduced somewhat the yield of tea. There was just sufficient disease here and there for the query under discussion to be put to the tea plant. The question on these particular gardens was not posed deliberately, but quite by accident. While this series of trials was in progress, example after example came to my notice in which such small applications of compost as five tons to the acre were at once followed by a marked improvement in growth, in general vigour, and in resistance to disease. Although very gratifying in one sense, these results were distinctly disconcerting. If humus acts only indirectly by increasing the fertility of the soil, time will be needed for the various biological, physical, and chemical changes to take place. If the plant responds at once, as was obviously the case, some other factor besides a general improvement in soil fertility must be at work. What could this factor be? It was clearly some agency which enabled humus to effect directly and very quickly the nutrition of the plant.

In a circular letter issued on 7th October 1937 to correspondents in the tea industry I suggested that the most obvious explanation of any sudden improvement in tea observed after one moderate application of compost could only be due to the effect of humus in stimulating the mycorrhizal relationship, which I afterwards discovered had been observed in Java in the roots of this crop. It seemed to me that this association must be present and that it would enable the fungous factor in the partnership to transfer the digestion products of protein into the sap and then into the green leaf. The virtues of humus could thus be moved from soil to plant in a very short space of time. This would enable the plant not only to resist disease, but would also explain the marked improvement in the yield and quality of tea which resulted from dressings of compost. I saw all this in imagination, as it were, on 7th October 1937 as a likely hypothesis to explain the facts. What set these ideas in train was a perusal of Dr. M. C. Rayner's work on conifers at Wareham 1 in Dorsetshire, where small additions of properly made compost had led to spectacular results most easily explained by the establishment of the mycorrhizal association. (An account of this Wareham work has since been published in 1944 in book form under the title--Problems in Tree Nutrition--by Messrs. Faber and Faber, London.)

At this juncture a group of tea companies which had adopted the Indore Process asked me to visit their estates in India and Ceylon. In the course of this tour, which lasted from November 1937 to February 1938, I examined the root system of a number of tea plants which had been manured with properly made compost, and found everywhere the same thing--numerous tufts of healthy-looking roots associated with rapidly developing foliage and twigs much above the average. Both below and above ground humus was clearly leading to a marked condition of wellbeing. When the characteristic tufts of young surface roots were examined microscopically, the cortical cells were seen to be literally overrun with mycelium to a much greater extent than is the rule in a really serious infection by a parasitic fungus. Clearly the mycorrhizal relationship was very much involved: my hypothesis was abundantly confirmed: the tea plant had a message to deliver on the disease question. My hasty and imperfect observations made in the field and in the course of a very strenuous tour--during which many estates were visited in detail and many lectures were delivered to groups of planters--were confirmed and extended by Dr. M. C. Rayner and Dr. Ida Levisohn who examined a large number of my root samples, including a few in which artificials only were used or where the soils were completely exhausted and the garden had become derelict with perhaps only half the full complement of tea plants. In these latter cases the characteristic tufts of normal roots were not observed; development and growth were both defective; the mycorrhizal association was either absent or poorly developed. Where artificials were used on worn-out tea, infection by brownish hyphae of a Rhizactonia-like fungus (often associated with mild parasitism) was noticed. But whenever the roots of tea manured with properly made compost were critically examined, the whole of the cortical tissues of the young roots always showed abundant endotrophic mycorrhizal invasion, the mainly intra-cellular mycelium apparently belonging to one fungus. This fungus was always confined to the young roots and no invasion of old roots was observed. In the invaded cells the mycelium exhibits a regular cycle of changes from invasion to the clumping of the hyphae around the cell nuclei, digestion and disintegration of their granular contents, and the final disappearance of the products from the cells. In this way the digestion products of the proteins of the fungus pass into the cell sap and then into the green leaves.

Humus in the soil, therefore, affects the tea plant direct by means of a middleman--the mycorrhizal association. Nature has provided an interesting piece of living machinery for joining up a fertile tea soil with the plant. Obviously we must see that this machinery is provided with the fuel it needs--continuous dressings of properly made compost. I saw on several occasions the response of the tea plant, which had been attacked by disease, to small dressings of compost. I was amazed by the way even a single application had reduced the amount of infection and started the tea bushes well on the way to complete recovery.

The tea plant had now answered the question: What must be done to me to be saved? It is nothing less than the restitution of the manurial rights this plant enjoyed in its forest home--regular supplies of freshly prepared compost.

One difficulty was encountered and partly overcome in this restitution of manurial rights. In some of the tea areas the gardens were so closely jammed together that it was not possible to maintain the head of cattle needed to provide the animal manure for making first-class compost. I suggested that in such cases pigs would be the easiest livestock to keep and that the cost of the pig food brought on to the gardens could be found by reducing the amount of artificial manure that would be needed. But where land was available, steps were taken to increase the head of other livestock to make the necessary animal manure.

One interesting case of introducing cattle into the tea gardens solely for their manure came to my notice from Africa. When Viscount Bledisloe returned to England from his African mission, where he had been Chairman of a Royal Commission connected with the affairs of the Rhodesias and Nyasaland, he presented me with an enlarged set of the photographs he had taken on compost making, the virtues of which he constantly brought to the notice of the various local governments with whom he came in contact. In this way he did much of the spade work which was necessary to make South Africa compost-minded. One of these photographs, taken at Messrs. J. J. Lyons & Company's estate at Mlange, showed the cattle which the tea gardens of Nyasaland were beginning to keep solely for compost making (Plate III). This, indeed, was proof positive of progress and of enterprise. If the tea gardens of Africa can go to the trouble of maintaining cattle for the sake of the urine and dung they produce, what is to prevent other plantation industries all over the world doing the same? It is impossible to farm for long without livestock. It is equally impossible to maintain the overseas plantations in an efficient condition without these living manure factories for producing two of the essentials for making humus. Like tea, all these plantation crops--coffee, cacao, sugar-cane, cotton, sisal, maize, coconuts, bananas, citrus fruit, grapes, apples, pears, peaches, and so forth--are mycorrhiza formers. All need the digestion products of fungous protein to maintain the power to reproduce themselves, to provide high-quality crops, and to resist the onslaught of insects and fungi.

PLATE III. LIVESTOCK FOR MAKING COMPOST ON A TEA ESTATE IN AFRICA.

But cases of disease occur in tea which cannot be remedied by getting the surface soil into good fettle. The tea is a deep-rooting plant and makes great use of the lower roots to keep up the water supply during dry weather. These deep roots must, therefore, function properly. There must be no waterlogging due to stagnant water held up by impermeable layers in the subsoil. This condition invariably results in root disease duly followed by the death of the plant. The only example of such disease of any consequence I met with during my second tour in India and Ceylon was a root fungus which appeared here and there and destroyed the bushes over small areas particularly on the laterite soils of South India. The real cause of the trouble appeared to be some interference with drainage in the lower layers of the soil, which reduced the vitality of the tea and prepared the way for the parasite. Such diseases might be dealt with most easily by Swedish pillar-drains--vertical pits, dug well below the layer under the laterite holding up the stagnant water, and afterwards filled with large stones.

At the Gandrapara estate on the flat stretches of the alluvium of the Bengal Dooars I saw one of the best examples in my experience of successful surface drainage under a high monsoon rainfall, which I was told had proved very useful in the prevention of root disease. On this fine property, very deep and narrow minor earth drains had been constructed among the tea and connected up with wider major ditches which carried off the surplus water to the natural drainage lines. The system was based on a contour survey and had been carried out by a competent engineer. The minor drains could not easily be detected, as the tea bushes on either side met above the drains, forming everywhere a continuous green table. With the combined help of the excellent top shade and this green table the heavy monsoon downfalls were converted into fine spray, which was readily absorbed by the heavily composted surface soil without any great silting up of these minor drains. I had studied surface drainage in many parts of the world, including some of the best examples Italy has to provide, and had carried out drainage schemes on the land in my own charge, but none of these came up to the Gandrapara standard. I mentioned this fact at a lecture to a group of local tea planters at Gandrapara. By chance the engineer who had designed the local scheme was present. His grateful reaction to my chance remarks will remain as one of my pleasantest recollections.

PLATE IV. GUAVA (Psidium Guyava, L.) No. 1--Superficial and deep roots (November 23, 1921). No. 2--The influence of soil texture on the formation of the rootless (March 29, 1921). No. 3--The root-system under grass (April 21, 1921). No. 4--Superficial rootlet growing to the surface (August 28, 1921). No. 5--Formation of new rootless in fine sand following the fall of the ground water (November 20, 1921). No. 6--Reduction in the size of leaves after twenty months under grass (right).

The superficial character of the conventional investigations on the diseases of tea will be clear from what has been set out above. Nothing is to be gained by starting research on any future tea disease at the wrong end. Investigation must always begin with the soil. If the mycorrhizal association is not working properly, this must be put right in the first place. The drainage of the soil round the deep roots must also be effective. In all probability the result will be the rapid disappearance of pests. Proceeding in this way, diseases can be made very useful for keeping a tea garden up to the mark as regards manuring and soil management.

CACAO (THEOBROMA CACAO)

A good deal of time was spent by me in Grenada about 1901 on the study of the fungous diseases of cacao. Visits were also paid to a number of cacao estates in Trinidad and Dominica. The main troubles were three: die-back of the leaders on low-lying areas (caused by poor drainage), pod, and bark diseases. A new fungous pest--the witch broom disease--had just made its appearance in Surinam, but had not then spread to Trinidad and the other islands. It has since become a serious trouble in the West Indies.

Among the many estates visited was a small plantation in Grenada owned by the late Rev. G. W. Branch, which stood out from the rest of the island by virtue of the heavy yields of high-quality beans; the fact was ascertained that these cacao trees were always manured with farmyard manure. Although a paper was read by the owner at one of the West Indian Conferences in the early years of this century and full details of the method of manuring were given, it never struck anyone that here in a nutshell was the solution of the main problem of cacao, namely, mixed farming and the preparation of plenty of freshly prepared compost for the cacao trees. Everybody without exception who attended this meeting was labouring under the thraldom of the NPK mentality and was only able to think in terms of so many pounds to the acre of this or that artificial manure. Though many were impressed by these Grenada results, they seemed incapable of facing up to their very obvious implications. All this happened about 1901.

In 1908 in the course of a visit to Ceylon I saw these Grenada results repeated, but on a much larger scale, at the Kondesalle cacao estate near Kandy. Thirty years later--in 1938--when on my tour of the tea estates of India and Ceylon I resumed my interest in cacao and re-visited Kondesalle, at which the finest cacao beans I have ever seen are being produced. I again observed no cacao diseases on this property and was not told of any by the manager or by his assistants. The trees appeared exceedingly healthy and here again, as on the small Grenada plantation, livestock--in this case, pigs and Hissar cattle--were kept for producing the farmyard manure applied to the cacao trees.

During this tour samples of the surface roots of cacao at Kondesalle were fixed and sent to London for examination by Dr. Rayner. The results are referred to in my report on this tour in the following words:

'Cacao. Dr. Rayner examined the surface roots of cacao from Kondesalle (Ceylon) taken from a field which had been manured with farmyard manure. Sporadic mycorrhizal infection of endotrophic (i.e. intracellular) type was present. Compost is not yet being made on this estate. It will be interesting to see whether still better results than those now yielded by farmyard manure on this fine property could not be obtained if the cattle and pig manure were first composted with the estate wastes and used in the form of humus.'

It will be obvious that in both Grenada and Ceylon examples of how to grow heavy crops of high quality cacao, free from disease, have long been provided by accident, as it were. Meanwhile both these regions have been furnished with modern agricultural departments. The astounding fact is that no one in these organizations or in the planting community has understood the value or the significance of the lessons these two estates have to teach. Nevertheless, both indicate quite clearly how cacao will have to be produced in the future if the growing menace of disease is to be averted. As is well known, much of the cacao of commerce now comes from West Africa, where it is produced largely at the expense of the original stores of humus left by the forest. As in Grenada and Trinidad, these stores will not last for ever. After a time they will be used up and the day of reckoning will arrive. Indeed, this has already come.

In the West India Committee Circular of September 1944 an article appeared on the future welfare of this crop in the Gold Coast--the world's largest exporter of cacao. It appears that the industry is face to face with a crisis 'perhaps without equal in the history of any major tropical crop in the British Empire'.

Two factors are responsible for this state of affairs: (1) the swollen-shoot virus disease, first reported in 1936, and (2) capsid bugs. These two pests are being investigated at the Tafo Cacao Research Station established by the local Agricultural Department in 1938. The spread of these two diseases has been so rapid as to constitute a direct menace to the whole future of the industry. In 1943 a conference of research workers was held at Tafo, presided over by the Agricultural Adviser to the Secretary of State. A programme of future research in cacao was formulated. Plans were also made for the reorganization of the Tafo Station as the West African Cacao Research Institute, for which a director has been appointed.

There seems no doubt that what is needed to place the cacao industry of the Gold Coast on a sound foundation is not more research into cacao diseases, but the introduction of livestock into the areas growing cacao and the conversion of the wastes of the animal and the plant into humus, as Messrs. J. J. Lyons & Company have done on their tea estates in Nyasaland (p. 116). The Gold Coast cacao industry, which began to export produce at the beginning of the century, has obviously been living for the last forty years or so on capital--on the humus left by the original forest. This has now been used up and Nature has registered her usual protest in the form of disease. The West African cacao trees have been deprived of their manurial rights. The Kondesalle cacao estate in Ceylon indicates what should be done to put matters right. No committees, however well selected, and no amount of research, however devoted, will alter this obvious conclusion. The time has indeed come for the prodigal to return, to confess, and to start proper farming.

There is no doubt that the cacao industry all over the Empire could at once be restored by mixed farming and the systematic conversion into compost of all the vegetable and animal wastes available. The manufacturing interests in Great Britain which need a regular and reliable supply of cacao beans should at once use their influence and insist that this obvious reform be taken in hand forthwith.

One objection to this suggestion must be answered in advance. If a portion of the existing areas under cacao is devoted to mixed farming, how is the output to be maintained? The answer is: By virtue of the vastly increased yield and better quality of the beans, as well as the longer life of the trees. There is ample land in all the cacao-growing areas of the Empire for this crop and also for livestock: there is no reason why this reform should not be set in motion forthwith. Must we always wait for catastrophe before the simplest step forward can be taken? What has the agricultural research organization of the Colonies been doing to allow such a state of affairs as this Gold Coast cacao scandal to develop?

COTTON

The cotton crop suffers from many insect and a few fungous diseases. It has already been mentioned that one-quarter of the space of the last pre-war issues of the Empire Growing Cotton Review was devoted to disease. The alarming significance of the figures given can only be realized when it is remembered that cotton is a distinctly robust crop that does not need very intensive methods of farming to produce fair yields of fibre. Moreover, cotton should not exhaust the land very much, as the fibre of commerce contains little more than the cellulose manufactured from the gases of the atmosphere and the water in the soil; the flowers fall after the bolls set; the leaves of the crop mostly drop before the stalks are removed; the roots remain in the ground: the seed is very useful for feeding the work cattle. Provided, therefore, a fair proportion of the cotton seed is passed through the stomachs of oxen and other animals and the old stalks find their way back to the soil in the form of humus, this crop cannot possibly wear out the land to any appreciable extent. Further, as inter-cultivation between the rows has to stop when the flowers appear, a cotton crop always enables weeds to cover the surface which, when ploughed under, help to maintain the humus content of the soil. If the incidence of disease depends on the poverty of the soil, it would seem that there must be something very wrong somewhere in the current methods of cotton growing; otherwise these diseases ought not to occur. A cotton crop, if properly looked after, ought to be very free from pests.

During the years 1924-31 I had unique opportunities for the study of this crop, because during this period I held the post of Director of the Institute of Plant Industry at Indore in Central India, at which cotton was the principal crop. Indeed, the new institute could not have been founded or maintained without the help of large grants from the Indian Central Cotton Committee, which in turn was financed by a small annual cess on each bale of raw cotton exported from India or used in the local mills. This cess was naturally passed on to the multitude of smallholders who raised the crop. If, therefore, the Indian Central Committee could do something to help these men in return for their money, this new body and its various research workers would have justified their existence.

Before taking up an investigation of the cotton crop at Indore in 1924, a survey of cotton growing in the various parts of India was undertaken. At the same time, the research work in progress on cotton in other parts of the world was critically examined.

As regards cotton growing in India, the two most important areas are: (1) the black cotton soils of the Peninsula, which are derived from the basalt; (2) the alluvium of north-west India, consisting of deposits left in a deep chasm by the rivers of the Indo-Gangetic plain. Besides these there are small areas of garden cultivation in southern India, where American types of cotton are grown intensively under irrigation and where heavy crops of good fibre are the rule.

On the black soils there are thousands of examples which indicate the direction research on this crop should take. All round the villages of the Peninsula, zones of very highly manured land, rich in organic matter, occur. These are kept in good fettle by the habits of the people: the night-soil is habitually added a little at a time to the surface of the fields. On such zones cotton does well no matter the season; the plants are well grown and remarkably free from pests; the yield of seed cotton is high. On the similar but unmanured land alongside the growth is comparatively poor; only in years of well-distributed rainfall is the yield satisfactory. But even under the most adverse conditions one is amazed to see how the cotton plant manages to survive and to produce some kind of crop. Only the very hardiest plant could produce seed under such unfavourable circumstances. The limiting factor in growth on these black soils is the development, soon after the rains set in, of a colloidal condition, which interferes with aeration and impedes percolation. This occurs on all black soils, but organic matter mitigates the condition. As these soils dry out at the end of the rains, extensive cracking occurs which aerates the soil but also damages the roots and rapidly desiccates the soil. The varieties of cotton, therefore, must possess the power of rapid ripening, otherwise the bolls could not open in time. The growth period of any successful cotton on the rain-fed, black soil areas must be short; the plant must literally burst into cotton at picking time and show no tendency to linger in yielding up its crop. Two pickings at the most are all that is possible.

On the alluvium of north-west India a somewhat similar limiting factor occurs. Here cotton is grown on irrigation, which first causes the soil particles to pack and later on to form colloids. In due course the American varieties, whose root systems, compared with those of the indigenous cottons, are superficial, show by their growth that they are not quite at home. The anthers, the most sensitive portion of the flower, sometimes fail to open and to release their pollen: the crop is unable to set a full crop of seed. But this is not all. The ripening period, particularly in the Punjab, is unduly prolonged; as many as four pickings are necessary. Moreover, the fibre often lacks strength, quality, and life. The cause of these troubles is poor soil aeration, which in these soils leads to a very mild alkali condition. This, in turn, prevents the cotton crop from absorbing sufficient water from the soil. One of the easiest methods of preventing this packing and alkali formation is to increase the bacterial population by means of dressings of humus. In this way the soil is able to re-create a sufficient supply of compound particles to restore the aeration and improve the water supply needed by the cotton.

As regards disease, insects cause more damage to the crop than do fungi: there is more insect disease on the alluvium than on the black soils. The insect diseases on the alluvium mostly affect the bolls which, as we have seen, develop but slowly. If the cotton could be made to ripen more quickly, these boll diseases might be very considerably reduced.

The direction of research work on cotton was, therefore, disclosed by a study in the field of the crop itself. The problem was how best to maintain soil aeration and percolation. This could be solved if more humus could be obtained. At the same time, there appeared to be every chance that more humus would materially reduce, by speeding up maturation, the damage done to the ripening bolls by the various boll worms. Good farming methods, therefore, including a proper balance between livestock and cotton, seemed to provide the key to the cotton problems of India. Once the soils were got into good fettle and maintained in this condition, the question of improved varieties could then be taken up with every chance of success. To hope to overcome bad farming by improving the variety in the first place was an obvious impossibility, such a research policy amounting to a contradiction in terms.

A study of the research work on cotton which had been done all over the world did nothing to modify this opinion. Cotton investigation everywhere appeared to suffer from the fragmentation of the factors, from a consequent loss of direction, from failure to define the problems to be investigated, and from a scientific approach on far too narrow a front without that balance and stability provided by adequate, first-hand farming experience. The research workers seemed to be far too busy on the periphery of the subject and to be spending their time on unimportant details. This has naturally resulted in a spate of minor papers which lead nowhere except to the cemetery so providentially furnished by the Empire Cotton Growing Review. In Africa, particularly, much time and money have been wasted in trying to overcome, by plant-breeding methods, diseases which obviously owe their origin to a combination of worn-out soil and bad farming.

Steps were therefore taken at Indore to accelerate the work on the manufacture of humus which had been begun at the Pusa Research Institute. The Indore Process was the result. It was first necessary to try it out on the cotton crop. The results are summed up in the following table.

THE INCREASE IN GENERAL FERTILITY AT INDORE

Year	Area in acres of improved land under cotton	Average yield in lb. per acre	Yield of the best plot of the year in lb. per acre	Rainfall in inches
1927	20.60	340	384	27.79 (distribution good)
1928	6.64	510	515	40.98 a year of excessive rain)
1929	39.98	578	752	23.11 (distribution poor)

The figures show that, no matter what the amount and distribution of rainfall were, the application of humus soon trebled the average yield of seed cotton--200 lb. per acre--obtained by the cultivators on similar land in the neighbourhood.

In preparing humus at Indore one of the chief wastes was the old stalks of cotton. Before these could be composted they had to be broken up. This was accomplished by laying them on the estate roads, where they were soon reduced by the traffic to a suitable condition for use as bedding for the work cattle prior to fermentation in the compost pits. I owe this suggestion to Sir Edward Hearle Cole, who hit upon this simple device on his Punjab estate.

The first cotton grower to apply the Indore Process was Colonel (now Sir Edward) Hearle Cole at the Coleyana Estate in the Montgomery District of the Punjab, where a compost factory on the lines of the one at the Institute of Plant Industry at Indore was established in June 1932. At this centre all available wastes have been regularly composted since the beginning; the output is now about 8,000 tons of finished humus a year. Compost has increased the yield of cotton, improved the fibre, lessened disease, and reduced the amount of irrigation water by a third. The neighbouring estates have all adopted composting; many interested visitors have seen the work in progress. One advantage to the Punjab of this work has, however, escaped attention, namely the importance of the large quantities of well grown seed, raised on fertile soil, contributed by these estates to the seed distribution schemes of the Provincial Agricultural Department. Plant breeding, to be successful, involves two things--an improved variety plus seed for distribution grown on soil rich in humus.

The first member of an agricultural department to adopt the Indore method of composting for cotton was Mr. W. J. Jenkins, C.I.E., when Chief Agricultural Officer in Sind, who proved that humus is of the greatest value in keeping the alkali condition in check, in maintaining the health of the cotton plant, and in increasing the yield of fibre. At

Sakrand, for example, no less than 1,250 cart-loads of finished humus were prepared in 1934-5 from waste materials such as cotton stalks and crop residues.

During recent years the Indore Process has been tried out on some of the cotton farms in Africa belonging to the Empire Cotton Growing Corporation. In Rhodesia, for example, interesting results have been obtained by Mr. J. E. Peat at Gatooma. These were published in the Rhodesia Herald of 17th August 1939. Compost markedly improved the fibre and increased the yield not only of cotton, but also of the rotational crop of maize. The results obtained by the pioneers in India, therefore, apply to Africa.

Why cotton reacts so markedly to humus has only recently been discovered. The story is an interesting one, which must be placed on record. In July 1938 I published a paper in the Empire Cotton Growing Review (Vol. XV, No. 3, 1938, p. 186), in which the role of the mycorrhizal relationship in the transmission of disease resistance from a fertile soil to the plant was discussed. In the last paragraph of this paper the suggestion was made that mycorrhiza 'is almost certain to prove of importance to cotton and the great differences observed in Cambodia cotton in India in yield as well as in the length of the fibre, when grown on (1) garden land (rich in humus) and (2) ordinary unmanured land, might well be explained by this factor'. In the following number of this Journal (Vol. XV, No. 4, 1938, p. 310) I put forward evidence which proved that cotton is a mycorrhiza former. The significance of this factor to the cotton industry was emphasized in the following words:

'As regards cotton production, experience in other crops, whose roots show the mycorrhizal relationship, points very clearly to what will be necessary. More attention will have to be paid to the well tried methods of good farming and to the restoration of soil fertility by means of humus prepared from vegetable and animal wastes. An equilibrium between the soil, the plant, and the animal can then be established and maintained. On any particular area under cotton, a fairly definite ratio between the number of livestock and the acreage of cotton will be essential. Once this is secured there will be a marked improvement in the yield, in the quality of the fibre, and in the general health of the crop. All this is necessary, if the mycorrhizal relationship is to act and if Nature's channels of sustenance between the soil and the plant are to function. Any attempt to side-track this mechanism is certain to fail.

'The research work on cotton of to-morrow will have to start from a new base line--soil fertility. In the transition between the research of to-day and that of the future, a number of problems now under investigation will either disappear altogether or take on an entirely new complexion. A fertile soil will enable the plant to carry out the synthesis of proteins in the green leaf to perfection. In consequence the toll now taken by fungous, insect, and other diseases will at first shrink in volume and then be reduced to its normal insignificance. We shall also hear less about soil erosion in places like Nyasaland, where cotton is grown, because a fertile soil will be able to drink in the rainfall and so prevent this trouble at the source.'

Confirmation of these pioneering results soon followed. In the Transactions of the British Mycological Society (Vol. XXII, 1939, p. 274) Butler mentions the occurrence of mycorrhiza as luxuriantly developed in cotton from the Sudan and also in cotton from the black soils of Gujerat (India). In the issue of Nature of 1st July 1939 Younis Sabet recorded the mycorrhizal relationship in Egypt. In the Empire Cotton Growing Review of July 1939 Dr. Rayner confirmed the existence of mycorrhiza in samples of the roots of both Cambodia and Malvi cotton collected at my suggestion for her by Mr. Y. D. Wad at Indore, Central India, from both black cotton soil and from sandy soil from Rajputana.

The problem now to be solved in cotton production and in the control of disease is the discovery of the easiest way in which the present extensive methods of agriculture can be converted into more intensive methods. This involves a great increase in livestock in the existing cotton areas and the systematic conversion of the cotton stalks into humus. In this way the yield per acre can rapidly be increased and the fibre improved. The present supplies of cotton can, therefore, be produced from about two-thirds the area now under this crop. The land so released can be used for the production of food grains and fodder crops. A balanced agriculture is the key to the prevention of the diseases of cotton.

Every point here discussed was mentioned or suggested in the section on cotton in An Agricultural Testament published in 1940. It will be interesting to observe how long it will take such bodies as the Empire Cotton Growing Corporation and the Indian Central Cotton Committee to revise their research policies and to replace their laboratory workers by farmer-scientists.

RICE

The most important cereal in the world is rice. Moreover, it is a crop remarkably free from diseases of all kinds. Rice, therefore, should take high rank among Nature's professors of agriculture. A study of its cultivation might teach us much about the prevention of disease.

But the moment we embark on such a study we find no less than three of the principles underlying Western agricultural science flatly contradicted by this ancient cultivation.

In the first place, in many of the great rice areas of the world there is no such thing as a rotation of crops. Rice follows rice year after year and century after century without a break, without even a fallow year every now and then. Moreover, there is no falling off in yield and no sign of soil exhaustion. There is, therefore, no need of a continuous rice experiment of the Broadbalk pattern for the simple reason that such age-long experiments are to be seen everywhere. To begin a new one would be to carry coals to Newcastle.

In the second place, these continuous rice crops do not need those extraneous annual applications of nitrogenous manures which are considered to be essential for all cereals. The rice fields somehow manure themselves.

In the third place, the rice crop often covers vast areas of land in one unbroken sheet, thereby providing a paradise for insect and fungous diseases. But these do not occur: on the contrary, the rice crop is generally remarkably free from diseases of all kinds.

What is the secret underlying these unexpected and unconventional results? The beginning of the solution of the riddle will, I think, be found in the nurseries in which the young rice plants are raised before transplanting. These are always on well aerated and well manured land, the manure, as a rule, being well decayed cattle manure. The result is the rice seedlings become veritable arsenals of such things as nitrogen, phosphorus, and potash, all in organic combination. Moreover, the rice plant is a mycorrhiza former and so ample provision occurs even in the seedling stage for the circulation of protein between soil, sap, and green leaf. How important this building up of the rice seedling is will be clear, when it is realized that the transplanting process from well aerated soil to mud involves a completely fresh start in a new environment. This results in a delay of many days and, therefore, in the loss of a substantial proportion of the total growing period. Nevertheless, transplanting pays, because transplanted rice always gives a better yield than broadcast rice in which, of course, there is no delay in growth. Here we have a clear and definite lesson from the long experience of the Orient, namely, the vital importance of well-nourished seedlings. This applies in particular to crops like fruit, tea, coffee, cacao, tobacco, vegetables, and so forth. In all these well begun is half done.

But how does the rice manage to manure itself? The answer is provided by the nitrogen-fixing powers of the algal film found in rice fields. This algal film does three things: it aerates the water of the rice fields; it fixes a continuous supply of nitrogen from the atmosphere; it leaves behind a useful amount of easily decomposable organic matter. Nevertheless, more organic matter is needed in the rice fields beyond that supplied by the algal film and the roots of the old crop. How markedly rice benefits from compost has been proved at Dichpali in

India. The results have already been set out in Chapter V of An Agricultural Testament, pp. 80-2.

The problem now is to find more compost for the rice crop. Nature has already provided ample vegetable waste in the shape of the water hyacinth, an aquatic weed to be found in most of the rice-growing areas of the world. This water weed should be regarded as a heaven-sent gift of Providence for the rice-growing areas, as it provides not only large supplies of readily fermentable vegetable matter, but sufficient moisture for the composting process as well. All that is needed besides is a supply of cow-dung and urine earth, both of which are available locally. In Bengal, for example, the annual yield of rice could be vastly increased if only a national campaign for the composting of the water hyacinth could be set in motion. That this weed makes excellent compost has already been fully demonstrated: first at Barrackpore, near Calcutta, by Mr. E. F. Watson, O.B.E., the Superintendent of the Governor's Estates, Bengal, and later on some of the tea estates in Assam. No future rice famines in Bengal need be feared once full use is made of the vast local supplies of water hyacinth.

What is the explanation of the comparative immunity of the rice crop from disease? I think the answer is provided by the fact that rice is a mycorrhiza former and that this mechanism works not only in the rice nurseries, but also in the paddy fields themselves: nothing has interfered with this process, as artificial manures are unknown and such bad practices as over-irrigation are, from the nature of the case, impossible. Indeed, the behaviour of this crop as regards parasites supplies strong confirmation of the view that what matters most in crop production is the effective circulation of protein between soil and sap, followed by the synthesis of still more protein of the right kind in the green leaf. High quality protein will, in ordinary circumstances, always protect the plant against its enemies.

WHEAT

For nineteen years, 1905-23, I was engaged in a study of the wheat crop of India, which included work on the creation of new varieties. The records of the work on Indian wheat carried out at Pusa will be found in Wheat in India, published in 1908, and in a series of thirty-four papers issued by the Agricultural Research Institute, Pusa. A list of these papers will be found in The Application of Science to Crop Production, Oxford University Press, 1929, and a summary in Bulletin 171 of the Agricultural Research Institute, Pusa, 1928.

Pusa is situated near the eastern extremity of the area under this crop, where the wheat and rice tracts are intermingled and where there is more rice than wheat. As would be expected, both the soil and atmospheric conditions are distinctly on the damp side for wheat. All three of the common rust fungi--brown, yellow, and black rust--were much in evidence. In one respect this was an advantage in plant breeding. It was easy to arrange for abundant infecting material for testing the reaction of the various cultures to these parasites. I did nothing to destroy these rusts; I did everything possible to have them always at hand. The result was that my ideas as to the cause of fungous diseases were constantly being verified. If a variety of wheat is resistant to one or more of these rusts, it makes no difference at all how much infecting material rains upon it or how much diseased stubble is ploughed into the land. Nothing happens even in wet seasons which always favour infection.

In the course of this work some interesting observations on immunity were made. Among the types of wheat in the submontane tracts of North Bihar a number were found which were very seldom or never attacked by rust. They were, to all intents and purposes, immune. Unfortunately they all possessed weak straw and poor yielding power, and were only useful as plant breeding material. Should, in the future, any wheat breeder need such types, they could either be collected at harvest time or selected from the crop raised from bazaar samples of wheat from this tract.

Another wheat which was immune to all three rusts was the primitive species known as einkorn (Triticum monococcum). But this wheat never flowered at Pusa, remaining in the vegetative condition till harvest time. One year some of these dense tufts were allowed to remain in the ground till the rains broke in June. This species was not killed by the intense hot weather of April and May, but as the hot season developed it began to show signs of infection by some parasite. This proved to be black rust--an interesting example of the destruction of immunity by adverse weather conditions, and a very striking confirmation of Mr. J. E. R. McDonagh's views on the limits of immunity set by extreme climatic conditions (p. 179).

The most interesting case of wheat disease I met with in my tours was in an area of low-lying land in the Harnai valley in the mountains of the Western Frontier. Here I found wheat growing in wet soil, in which the aeration was poor and the general soil conditions more suitable for rice than for wheat. It appeared this area was always affected by eelworm, which, however, never spread to the adjoining wheat areas which continued almost without a break for at least 1,000 miles to the east. Through this valley there was a constant stream of all kinds of traffic both ways--towards Afghanistan to the west and towards the great cities of the plains in the east. Nothing was done to check the infection of the neighbouring wheat areas by preventing the cysts of the eelworm being carried by the feet of animals or men or by wheeled traffic. Infection both ways must have been going on without interruption for hundreds of years. But nothing had happened. Obviously the eelworm is not the cause of the trouble or no power on earth could have stopped the whole of the wheat areas of a sub-continent becoming infected. Before infection is possible the soil conditions must be favourable.

A similar case of eelworm on rice occurred in the deep-water rice areas of Bengal, where the disease is known as ufra. Again we have a heavily infected area in close contact with one of the greatest rice areas of the world. No precautions are taken to isolate the area and protect the surrounding rice from infection. There has been no spread of the trouble outside the small deep-water areas which favour the eelworm.

These two outstanding cases, I think, dispose of the eelworm bogey, which threatens to raise its head in this country in connection with the eelworm diseases of potato and sugar beet. The experts propose measures to control the potato crop so as to prohibit the movement of tubers from and into certain areas. They also recommend that infested areas should give up growing these crops for some years till the eelworm dies out naturally. Before these suggestions are accepted by the authorities consideration might be given to the significance of the two cases--wheat and rice--cited above, and also to the elimination of eelworm on farms and gardens in Southern Rhodesia by dressings of freshly prepared compost (p. 149).

Intimately bound up with the resistance of the growing wheat plant to disease is the way wheat straw can stand up to the processes of decay when used as thatch. Is there any connection between the life of a thatched roof and the manurial treatment of the land which produced the wheat straw? There is. Farmyard manure results in good thatch, artificials in bad thatch. This will be evident from the following extracts from an article entitled 'Artificial Manures Destroy Quality', which appeared in the News-Letter on Compost, No. 4, October 1942, p. 30:

'In the case of the wheat crop raised on Viscount Lymington's estate in Hampshire, careful records have been kept of the life of wheat straw when used for thatching. Wheat straw from fields manured with organic matter, partly of animal origin, lasts ten years as thatch; straw from similar land manured with artificials lasts five years.'

Interesting confirmation of this view on the life of wheat straw in thatch has been supplied in a recent letter dated 10th September 1942 from a correspondent (Mr. J. G. D. Hamilton, Jordans, Buckinghamshire), who writes:

'About five years ago, while visiting craftsmen in Wiltshire, I was told by two old thatchers in different parts of the county that the straw they had to work with now was not nearly so good as that which they had had in years gone by. Both gave as the reason the modern use of artificials in place of farmyard manure.'

Anyone owning a thatched building, who wishes to compare the virtues of compost with the harm done by chemical manures, can easily make use of the above experiences when the time comes to renew the roof. Alternate strips of the two kinds of straw will soon show interesting differences and will suggest a further trial--a comparison of the whole wheat bread made from the two samples of wheat.

VINE

One of the oldest crops in the world is the vine. Its original home is said to be in Central Asia whence it has spread everywhere. Even when outdoor conditions have made its cultivation impossible, it has been successfully grown under glass often, as in Holland, on a commercial scale. Such an ancient branch of crop production might, therefore, have much to teach us about disease and its prevention.

During some thirty years, from 1910 to 1939, I came in close contact with this crop, which I soon began to regard as one of my ablest teachers. The instruction I received falls naturally into three independent courses which can best be dealt with in order.

From 1910 to 1918, the summers of which were spent in the Quetta valley on the Western Frontier of India, I saw a good deal of grape growing in desert areas, as it had been succe